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Francis Bacon and his Contemporaries

Edited by

Claus Zittel, Gisela Engel, Romano Nanni,
and Nicole C. Karafyllis

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His current research focusses on the uses of mathematics in seventeenth- and eighteenth-century England, while his doctoral work examined mathematical theories of music from that period.

His publications examine several topics in those areas. Two books—a co-edited edition of the writings of the musical theorist John Birchensha, and a book based on his doctoral thesis—are currently in press, and he is working on a third, a textbook entitled *How to Read Historical Mathematics*.

Sophie Weeks has recently completed her doctoral thesis on Francis Bacon's science of magic at the University of Leeds. She is currently a Junior Research Fellow at Homerton College, Cambridge where she is investigating Bacon's concept of the unity of the sciences. The resulting monograph will examine his notion that rules for the government of human behaviour in political, social, and moral spheres should be grounded on a materialist natural philosophy. She is also working on seventeenth-century Baconian experimentalists (with C. Kenny).

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INTRODUCTION

Claus Zittel

The essays in the present volume attempt to historically reconstruct the various dependencies of philosophical and scientific knowledge of the material and technical culture of the Early Modern era and to draw systematic conclusions for the writing of Early Modern history of science. The volume's title – 'Philosophies of Technology' – however, contains several stumbling blocks. First of all, one could and should object to the anachronism, for the term 'technology' was first coined in 1777 in Johann Beckmann's *Anleitung zur Technologie, oder zur Kenntniß der Handwerke, Fabriken und Manufakturen, vornehmlich derer, die mit Landwirtschaft, Polizey und Cameralwissenschaften in nächster Verbindung stehen.*[1] The term 'technology' replaces older designations such as *historia artificalis* or *technica*, which referred to the theoretical discipline of mechanics as the study of motion, the mathematical study of motion, as well as the *artes mechanicae*, in short, the activities of skilled labour which were differentiated from the 'liberal arts'.[2] There was a particularly close connection between the *artes mechanicae* and the invention, construction, and use of machines in the Early Modern era. As practical arts, they increasingly undermined the old Aristotelian differentiation between artificial (i.e. produced by humans) and natural things.[3] The broad signification which the expression *ars* retained well into the 17th century, and which included everything artistic, is consequently limited at the end of the 18th century through the expression 'technology' to all that is connected, in a modern sense, with the applied sciences, practical mechanics, engineering (above all, machine construction) and a praxis-oriented methodology. Until then, technologies in this narrower sense had not formed their own sub-field in the culture but had

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[1] Cf. Banse G. – Müller H.-P. (eds.), *Johann Beckmann und die Folgen. Erfindungen – Versuch der historischen, theoretischen und empirischen Annäherung an einen vielschichtigen Begriff* (Münster: 2001).

[2] Cf. Stöcklein A., *Leitbilder der Technik* (Munich: 1969), 31–35.

[3] Cf. for more specific information: Bennet J., "Mechanical Arts", in Park K. – Daston L. (eds.), *The Cambridge History of Science*, vol. 3: *Early Modern Science* (Cambridge: 2007), 673–695.

always been presented in connection with various scientific and skilled practices and an amalgamation of concepts from natural philosophy and cultural models.

The title of this volume also posits a strict relation between *philosophy* and technologies. According to current theories, however, this relation was marked by tension in the 17th century resulting from the frequently unsystematic and eclectic nature of 'technologies' which intensified into a conflict when practical knowledge was privileged above theoretical knowledge.[4]

The divisive transformation of humanist scholarly culture, the Scholastic school philosophy, as well as magic in the form of a philosophy of practice is always associated with the work of Francis Bacon. Bacon is, thus, an indispensable figure for the historical and systematic investigation of the complex interdependencies among science, technology, philosophy and society, advocating as he did a scientific ideal inspired by the concept of cooperation in service of the commonwealth and contributing to European sciences and philosophy by successfully arguing for and propagating experiment and controlled observation as fundamental to empirical research. His philosophy gave birth to the scientific dream of modernity that the advancement of society goes hand-in-hand with the unimpeded development of all technologies.

The examination of Bacon's experimental philosophy and its complex role in the formation of the Modern[5] is thus the starting point for a discussion of the guiding questions of this volume: Were developments in science and technology independent of one another – with technology on the one hand, philosophy and science on the other? Or in what sense do technology and technical development form part of what might be considered a shared European cultural heritage? What is the impact of technical models on the structuring of knowledge production in natural philosophy, natural history and the philosophy of history? How did technical models serve as explanatory models for the world at large? What was the level of technological development during Bacon's lifetime? What concrete form did the interconnection of technologies with other cultural practices take? Alongside the great heroes of scientific

[4] Gaukroger St., *Francis Bacon and the Transformation of Early-Modern Philosophy* (Cambridge: 2001), 14–18.

[5] Cf. on this: Engel G. – Karafyllis N. (eds.), *Technik in der Frühen Neuzeit – Schrittmacher der europäischen Moderne/Zeitsprünge. Forschungen zur Frühen Neuzeit*; vol. 8, no. 3/4 (Frankfurt am Main: 2004).

history, who were the influential actors? Do such simple differentiations between a culture of skilled-labour, of unplanned "doing", on the one hand, and a scientific culture, on the other, stand up to more precise historical analysis? How strongly was the development of theoretical knowledge in the Early Modern era connected with particular objects and instruments, thus on the material culture of the time?

Consequences for the historiography of the Early Modern era can also be indicated. The history of philosophy and the history of technology generally have very little to do with one another. On the one hand, the history of philosophy focuses primarily on the study of a few canonical texts and, thus, at the same time, almost always privileges an understanding of philosophy that suggests it is independent of cultural contexts and technological developments. Philosophy is understood as something 'written in books', and the role of instruments and technical innovations for the development of philosophical theories seldom comes into focus.[6] On the other hand, the history of technology is often characterized by tunnel vision, with its studies of local innovations or broad surveys which devote little attention to the philosophical and aesthetic[7] implications of technical phenomena. The more the history of technology opens itself to contemporary the newer history of science, the less likely it is to fall prey to this narrow perspective.[8]

At least since Shapin and Schaffer's pioneering study *Leviathan and the Air-Pump*,[9] the view in Early Modern histories of science has finally been accepted that, just as in the Ancient and Medieval eras, science and philosophy cannot be separated in the Early Modern period either. Medical doctors, physicists, and chemists in particular, as well as natural scientists employing an experiment approach, referred to themselves as philosophers. For Leibniz, Descartes, Bacon and Boyle,

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[6] In this regard, Biagioli M., *Galileo's Instruments of Credit. Telescopes, Images, Secrecy* (Chicago: 2006); Reeves E., *Galileo's Glassworks* (Harvard: 2008); Wilson C., *The Invisible World: Early Modern Philosophy and the Invention of the Microscope* (Princeton: 1995), among others, are exemplary models.

[7] Important exceptions are: Lefèvre W. (ed.), *Picturing Machines 1400–1700* (Cambridge, Mass.: 2004); Schramm H. – Schwarte L. – Lazardig J. (eds.), *Kunstkammer, Laboratorium, Bühne. Schauplätze des Wissens im 17. Jahrhundert* (Berlin: 2003); Schramm H. – Schwarte L. – Lazardig J. (eds.), *Instrumente in Kunst und Wissenschaft. Zur Architektonik kultureller Grenzen im 17. Jahrhundert* (Berlin: 2006); Holländer H. (ed.), *Erkenntnis, Erfindung, Konstruktion. Studien zur Bildgeschichte von Naturwissenschaften und Technik vom 16. bis zum 19. Jahrhundert* (Berlin: 2000).

[8] On this cf.: Golinski J., *Making Natural Knowledge* (Cambridge: 1998).

[9] Shapin S. – Schaffer St., *Leviathan and the Air-Pump* (Princeton: 1985).

the explanations of such natural phenomena as magnetism, rainbows, *horror vacui*, air pressure and gravity naturally fell within the realm of philosophy. The debate about experimental facts was simultaneously a debate about what could be considered a fact at all and thus constituted a theoretical conflict. This state of affairs, as Christoph Lüthy recently put it, should ultimately *force historians of philosophy to become historians of science and vice versa*.[10]

Nevertheless, as Lüthy has shown in numerous prominent examples, the focus on philosophical texts employing systematic argumentation has remained defining for contemporary historiography, despite the general awareness of the broad understanding of philosophy in the Early Modern era.[11] Such is not the case, however, for the new, expansive *Cambridge History of Early Modern Science*,[12] which includes an exemplary broad spectrum of topics in natural philosophy, science, technology, scientific objects, instruments and art. The essays in the *Cambridge History* are dedicated to an in-depth exploration of the epistemic core of technical developments in their socio-cultural contexts. Typically, however, it does not present itself as a 'History of Early Modern Philosophy'.

To offer a more concrete explanation, I would like to turn to Descartes. In rule ten of his so called '*Regulae*', in his first draft of a new method of philosophy, René Descartes explains how to make use of a new kind of practical sagacity, based upon acquired skill, experience, subtle wit and cunning. This sagacity should make the ingenium capable of detecting patterns of organization in unknown facts and putting these new patterns in relation to other forms of organisation. But how do you learn to use such sagacity, particularly for someone lacking a strong natural inclination to independent research? According to rule 10, one should undergo mental training, running through in their mind various organizational forms:

> In order to sharpen the intelligence, it should be exercised in searching for things that have already been discovered by others and it should review methodically even the most trivial results of human skill, especially those that deploy or presuppose order.

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[10] Lüthy Chr., "What to Do with Seventeenth-Century Natural Philosophy? A Taxonomic Problem", *Perspectives on Science* 8 (2000), 164–195, here: 166.

[11] Positive counterexamples are: Rossi P., *Philosophy, Technology, and the Arts in the Early Modern Era* (New York: 1970); Pérez-Ramos A., *Francis Bacon's Idea of Science and the Maker's Knowledge Tradition* (Oxford: 1988).

[12] Park K. – Daston L. (eds.), *The Cambridge History of Science*, vol. 3: *Early Modern Science* (Cambridge: 2007).

> But since every intelligence is not disposed by nature to investigate things by its own efforts, this proposition teaches that we should not initially undertake the most difficult and arduous things, but should first tackle some very simple and trivial arts, and primarily those in which order is most evident – such as those of artisans who weave tapestries and carpets, or of women who do needlepoint or weave threads of various textures in infinitely many ways [...] It is surprising how much all these things exercise one's intelligence.[13]

Thinking, weaving, knitting: if the eye is trained in recognising patterns, the ingenium can be helped along in the discovery of structural analogies between apparently different phenomena.

Descartes' appeal to the carpet weavers[14] is striking but represents no exception in the early 17th century. However, I chose the Cartesian example in order to show that even Descartes, as the supposed opponent of Baconian sciences, was quite certain about the necessity of sustaining theoretical knowledge through learned experience, maker's knowledge, and observations. Descartes also followed the Baconian program of learned experience, that new knowledge should be discovered by ingenious adaptation of existing knowledge rather than by formal inference from fundamental principles (*De Augmentis*).

All forms of available knowledge, hence no longer chiefly that presented in books, should become a resource for the generation of new knowledge. To understand this knowledge in its diversity and to continually expand it with new research can only take place, according to Bacon, through a collective effort in the gathering of experiences of all kinds, in examining and sifting through knowledge, and in well-planned teamwork for generations beyond the boundaries of professional constraint. Philosophy and every-day technical practices prove to be bound together. On the basis of the mechanical arts, 17th-century natural philosophy develops a correspondingly technological (and particularly with Bacon and his successors a masculine ruling) metaphorical language which would long dominate the representations of humans, mind and nature.[15] In the face of such strong ties between

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[13] Descartes, *Regulae*, in: *Œuvres de Descartes* [= AT], ed. Ch. Adam – P. Tannery, 11 vols. (Paris: 2nd ed.: 1971–1975), vol. XI 404.

[14] Cf. Nanni R., "Machinae ad maiestate imperii e macchine della manifattura tessile", in: Engel G. – Karafyllis N. (eds.), *Technik in der Frühen Neuzeit – Schrittmacher der Europäischen Moderne* (Frankfurt am Main: 2004), 409–441.

[15] Cf. Scholz S., "The Mirror and the Womb: Conceptions of the Mind in Bacon's Discourse of the Natural Sciences", in *Women. A Cultural Review* 3/2 (1992), 159–166.

theoretical and practical knowledge, it clearly makes little sense to think in terms of a division between 'high science', which aims at truth, and 'low science', which aims at usefulness.

It is, moreover, hardly possible to present a unified paradigm of an interpretive example for all the various technological developments, including their interconnections with philosophy and science. Just as the supposed scientific elite utilise the arsenal of practice, engineers and practitioners attempt to ennoble their activities by anchoring them in the high discourse of their era and to bolster their discoveries and constructions through philosophical or theological considerations.

The Cartesian example also makes it clear, more over, as is always emphasised in Early Modern histories of science, that this interconnection served not only to drive the scientific revolution of the 17th century. Parallel to this, in the space of only a few decades, six crucial instruments were invented: the telescope, the microscope, the air pump, the pendulum clock, the thermometer and the barometer. Naturally, they made it possible to carry-out experiments and make measurements which had previously been unthinkable. Nevertheless, we cannot afford to limit our historical focus to these few inventions. A wealth of other inventions and technologies employed and experimented with in the philosophical communities inspired by Leonardo Da Vinci and Bacon also provides practical knowledge relevant to the emergence of so-called mechanical philosophy.

While Descartes' 1626 proposition shows that the knowledge employed by weavers gained new respect as an intellectual resource, lens makers, machine builders, musical instrument makers, milk maids producing butter and sailors also became important sources for him. Bacon and William Gilbert not only made new discoveries but also discovered new methods in the reports of sailors and pilots and navigators. In their attempt to establish a new experimental science, Fabricius da Aquapendente studied mills, Paracelsus referred to woodworkers, while Bacon looked to sailors and others. Diviners, physicians, civil and architectural engineers, pyrotechnicians, artillerists, oven builders, specialists in hydraulics, shipbuilders, potters and design techniques, workshops, alchemical laboratories, military technologies[16] (and so

[16] Cf., Parker G., *The Military Revolution. Military Innovation and the rise of the West, 1500–1800* (Cambridge: 1988). Up to now useful is, Jaehns M., *Geschichte der Kriegswissenschaften, vornehmlich in Deutschland*, 3 vols. (Munich: 1889–1891).

on) can all be considered furnishers and sources of new methods and models for Early Modern cultures of knowledge.[17]

With the broadening of the scope of recent histories of science to include various technologies – and by integrating practical knowledge and theoretical contexts – an image of knowledge has emerged of a social environment in which philosophers and inventors of machines relied upon communication, collaboration, exchanges of experimental and observational reports, and patronage. New financial risks and strategies, new tactics for disseminating knowledge claims and secretive practices emerged, and new relationships concerning the changing role and significance of practical knowledge and technologies with respect to scientific theories and the traditional metaphysical foundations of knowledge also require further examination. Nevertheless, we should keep in mind that there may always be a difference between the ideals of knowledge based on experience and the practice of experimental research or technological invention, which are all too often concealed in later historical reconstructions of the Early Modern period.

The sphere of that which qualifies as 'technological' is ever expanding. Reference is made not only to the classic texts on technology and the history of machines, but the history of technology is now understood as an element of cultural history, alongside philosophy and the arts, as having contributed to the mobilisation of metaphors and the development of ways of thinking. Technical metaphors, technological models and inventions can thus be found not only in machine books of the Early Modern era[18] but also, for example, in texts like Descartes' *Discours de la méthode*, in art treatises and literary works.

It is in this context – however briefly sketched – that the essays in the present volume, *Philosophies of Technology*, intersect. The book is organised strictly along interdisciplinary lines. Whereby "interdisciplinarity" is not achieved merely by collecting essays from various disciplines into a single volume; rather, the problematic addressed in each individual essay necessitates the crossing of traditional disciplinary boundaries, reflecting a genuinely interdisciplinary perspective on its subject.

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[17] On this, Cf.: Lefèvre W. – Renn J. – Schoepflin U. (eds.), *The Power of Images in Early Modern Science* (Basel: 2003).

[18] The broadest overview of the machine books of the Early Modern era are in: Olschki L., *Die Literatur der Technik und der angewandten Wissenschaften vom Mittelalter bis zur Renaissance*, 3 vols. (Heidelberg: 1919). A newer account can be found in: Popplow M., *Neu, nützlich und erfindungsreich. Die Idealisierung von Technik in der frühen Neuzeit* (Münster-New York: 1998).

Instead of summarising the arguments of each contribution, my brief discussion of the essays collected here groups them thematically, touching on its key problematic. Despite the orientation of the collection on the history of science, only three of the essays come from the specialised discipline (Epple, Weeks, Borelli), while the rest come from such disciplines as philosophy, English, history of technology, legal history and art history.

The examination of Bacon's understanding of technology naturally constitutes a focus of this volume. The limited research thus far on the concrete relation of Bacon to the technical developments of his time has tended to point in sweeping gestures to Bacon's call for the replacement of scholarly culture with scientific culture, an appeal, so the argument goes, based on the juxtaposition of the new, progressive mechanical arts, on the one hand, and tradition-bound philosophy, on the other. In his standard work on the history of technology, Paolo Rossi formulates the still generally accepted assessment: 'Virtually the whole work of Francis Bacon addressed itself to the task of replacing a culture of rhetoric-literary type by a culture of a technico-scientific type.'[19]

This depiction is now being revised from various perspectives: Romano Nanni demonstrates that important technological changes proclaimed by Bacon to be innovations had, in fact, already been achieved much earlier; Sophie Weeks investigates the role of magic and its experimental practices, postulating that Bacon's understanding of mechanics does not have to be seen in strict opposition to magic, as Bacon himself sometimes suggested, but rather represents a transformation of magical practices. Luisa Dolza argues that through a stronger embedding in the culture of practitioners in England and on the continent, particularly in the so-called 'Machine Theatre', it was moreover clear that theology and the new technology were not oppositional, as the often theological and philosophical foundations of machine books and technical inventions illustrates. Dana Jalobeanu's examination of the discrepancies and connections between Bacon's scientific utopia in *New Atlantis* and the collection of experiments *Sylva Sylvarum*, two essays which were published together in a single volume, offers new insights into Bacon's particular rhetorical and fictional strategies. The

[19] Rossi P., *Philosophy, Technology, and the Arts in the Early Modern Era* (New York: 1970) 80.

dissemination of new technical utopias, as she suggests, by no means stands in opposition to the rhetorical tradition but rather feeds on it. On the other hand, Jürgen Klein interrogates the potential model of artists' workshops as a factor in the development of Bacon's philosophy, especially in light of the fact that the young Bacon had very likely attended lectures from Bernard Palissy in Paris and allegedly made a secret tribute to him in his early text, *Redargutio Philosopharum*.

Andrew Borlik maintains that Cornelis Drebbel is personified in the figure of the inventor of the barometer in *New Atlantis*. This essay marks the starting point for a second group of essays concerned with the history of instruments and their role in the formation of philosophical theories. Arianna Borelli focuses in particular on the history of barometers, in the wake of whose invention it was suddenly possible to make visible previously invisible movements of air. As can be shown in detail, this invention influenced in various ways the development of philosophical methodology in Giambattista della Porta, Francis Bacon, René Descartes and Robert Fludd. Along with Cornelis Drebbel, practitioners such as Salomon de Caus, Jacques Besson or Palissy, influenced the conceptual world of 17th-century natural philosophers with their mechanical inventions, even to the point of creating metaphors. Experimentation with musical instruments also played an important role in the development and transformation of early modern knowledge systems. Benjamin Wardhaugh analyses the relation between specific material objects, such as music instruments, and science in his essay, examining the way in which various uses of 'harmony' can illuminate mechanical, mathematical and experimental approaches to sound and music in Early Modern natural philosophy.

Another group of texts looks at technical metaphors, paying particular attention to the explanatory function of technical models in Bacon (Sophie Weeks), Harvey (Jarmo Pulkkinen) and Descartes (Andrés Vaccari, Claus Zittel). The special relevance of hydraulic and hydrodynamic models crystallizes here, for example, in the description of the human body. Hydrodynamic processes, in particular, can hardly, if at all, be reconciled with a rigid, machine-like understanding of mechanics. This leads to the conclusion that later conceptions of mechanics are much too narrow for that of the 17th century in order to conceptually grasp all that was understood at the time as mechanical processes; thus, for example, that historiographical models of the body as a machine or the world as a clock represent simplified projections back onto the era. This same phenomenon helps explain, as Staffan Müller-Wille

points out in the field of botany, how the impact of Bacon's scientific reform, including its theological implications, was largely ignored in later natural history.

In the 18th century, in other areas of natural philosophy the narrow understanding of mechanics dominated and some scientists, in express opposition, designed a 'sentimental hydraulics' based, as Thomas Brandstetter argues, on a firm rejection of traditional mechanistic constructions. There was a shared conviction that gearwheels, levers and other classical machine elements could not be added to the economy of nature. For this reason, numerous inventors struggled to design instruments which functioned without mechanical parts. With hydraulic and pneumatic constructions, the hidden forces of nature were to be harnessed and the disadvantages of conventional machines simultaneously avoided. Precisely because they could be so readily introduced into the natural economy such constructions also promised comprehensive political and social reforms.

Brandstetter's essay on hydraulics and essays by Moritz Epple and Daniel Damler are dedicated to another important area, the cultural dimension of spectacular hydraulic constructions such as the *Artifico* in Toledo, constructed by Juanela Turriano (Damler), which at the time was admired as a wonder of the world by Cervantes, Quevedo, and Lope de Vega. This perspective allows us to scrutinize, in turn, the conventional image of the Catholic Spanish monarchy as an enemy of science.

By analyzing the plans for the artificial fountains of Versailles and those of Sanssouci, Moritz Epple demonstrates how and to which degree in the 18th century the water lifting facilities and fountains provide the metaphors and the heuristic tools for the hydrodynamicists' theory. Hydraulic technology plays the role of a mediating field. Even though there was a gap between mathematical hydrodynamics and hydrotechnological practice in the 18th century, both mathematicians and engineers shared the utopian dream of mathematized hydrotechnology. Against this background Epple dicusses the complex interaction between hydrodynamics and hydrotechnology and argues that the scientific key concept of hydrodynamic pressure emerged from technically-oriented consideration.

Bertold Heinecke and Pablo Schneider demonstrate that Bacon's philosophy of technology exerted a powerful influence on literature and the arts. Heinecke delves into the close relationship between literature,

technical inventions and experimental natural philosophy with regard to the influence of Bacon on German poet Georg Philipp Harsdörffer. Harsdörffer developed a method of playful combination that productively merged technical and poetic invention. Schneider shows how Bacon's leitmotif of the call for scientific explanation and the unlimited nature of science, 'the open horizon', altered representations of power in English and French architecture.

All of these essays in this volume reflect the close interaction between technical models and knowledge production in natural philosophy, natural history and epistemology. It becomes clear that the technological developments of the Early Modern era cannot be adequately depicted in the form of a pure history of technology but rather only as part of a broader, cultural history of the sciences.

The present volume and a conference on the topic – which took place in Frankfurt am Main, Germany, 7–8 July 2006 – represent activities of the *Technics as Cultural Heritage/La Storia del Disegno Tecnico del Rinascimento e della Prima Modernità come Patrimonio Comune Europeo* network which was supported by the *Culture 2000* programme of the European Union's Directorate General Education and Culture. We would like to express our gratitude to the *Vereinigung von Freunden und Förderern der Johann Wolfgang Goethe Universität Frankfurt am Main e.V.* Thanks are also due to Staci von Boeckmann, Stephen Starck, and Henrike von Lyncker, who were very helpful in producing the English version of the manuscript.

PART I

BEGINNINGS

"INDUSTRIOUS OBSERVATIONS, GROUNDED CONCLUSIONS, AND PROFITABLE INVENTIONS AND DISCOVERIES; THE BEST STATE OF THAT PROVINCE": TECHNOLOGY AND CULTURE DURING FRANCIS BACON'S STAY IN FRANCE*

Luisa Dolza

> has there ever been an age more flourishing than our own in philosophy... and new inventions necessary to the life of mens
>
> Jacques Peletier du Mans, 1549[1]

Introduction

Paolo Rossi and other scholars have highlighted the influence on Francis Bacon of the magic-alchemical tradition, the revaluation of technical knowledge by 16th-century mechanists, the treatises on rhetoric and the arts of discourse.[2] Nonetheless, it remains unclear where and how Bacon could have been exposed to all such influences. Reading is a fundamental step in the advancement of learning, and there is no doubt that books, manuscripts, scholars and technicians circulated in Renaissance Europe.[3] Travel, however, is an equally formative experience. In September 1576, aged 16, Francis Bacon left Cambridge to accompany Sir Amyas Paulet, the English Ambassador, to France. Bacon spent

* Without implicating them in remaining errors, the author has benefited from the generous assistance of Andrea Goldstein and Romano Nanni, and from comments on an earlier draft of, amongst others, the editors of this volume.

[1] Jacques Peletier du Mans, *L'arithmetiques departie en quatre livres* (Poitiers: 1549). The volume was published also in 1554, in Lyon by de Tournes, and in Italian, by Gemma Frisius, in 1567.

[2] See Rossi P., "Baconianism", *Dictionary of the History of Ideas*, http://etext.virginia.edu/DicHist/dict.html, vol. I, 173–177, and its bibliography.

[3] On the transmission of technical knowledge, see Hilaire-Pérez L. – Verna C., "Dissemination of Technical Knowledge in the Middle Ages and the Early Modern Era. New Approaches and Methodological Issues", *Technology and Culture* 47 (2006) 537–563.

the following two and half years between Blois, Tours, Poitiers and Paris. In March 1579, Bacon was called back to England due to his father's death and, as far as we know, never crossed the channel again. Bacon's time in France has received scant attention, although scholars hypothesize that Bacon may have attended the lectures of Bertrand Palissy in this period.[4] Parisian cultural life at the time, however, went far beyond the famous ceramist.

The goal of this essay is to examine the rich environment to which the young Bacon was exposed during his stay in France, the persons he might have met, the texts he have might have read, and the way in which technology was represented and perceived in Paris during the religious wars. Bacon might have crossed paths, for example, with Jacques Peletier, whose texts were manifestoes of the practical uses of mathematics, or the *chirurgien du roy* Ambroise Parè, the jurist Jean Bodin, the architect Androuet du Cerceau or the engraver René Boyvin, as well as other *savants* such as François Beroald, Jacques Gohory and Jacques Besson. While we can be sure Bacon did not meet Ramus in person, since the famous Huguenot mathematician who spent hours discussing with technicians, mechanics and craftsmen perished in Saint Bartholomew's night, he might have read and discussed his books.[5]

Why this excursus on something that we cannot prove? Because at least some of the arguments that Bacon made in his writings were circulating, albeit in embryotic form, in Paris. The aforementioned authors were struggling with key questions that Bacon was also to consider – such as the relationship with the past, the role of technology in shaping modernity, the interactions between science and techniques. Moreover, the Parisians formed an academy, where scientists, technicians and physician could meet on a regular basis to present their work, confront ideas and create networks. While such bodies were still more a collection of individuals anchored to the past, rather than a new *unicum* turned to the future, as Bacon would later envisage in his writ-

[4] Rossi P., *Francis Bacon: From Magic to Science* (London-Chicago: 1967). He mentioned the hypothesis of Farrington, in "On misunderstanding the Philosophy of Francis Bacon", in *Science, Medicine and History, essays in honor of Ch. Singer*, vol. 1 (Oxford: 1953) 439–50. This hypothesis was first mentioned by Sir T. Clifford Allbut, *Palissy, Bacon and the revival of natural science*, in *Proceedings of the British Academy*, VI, 1913–14, 223 ff. On the idea of progress and value of technology: Rossi P., *Philosophy, Technology and the Arts in the Early Modern Era* (New York: 1970).

[5] On Ramus and his idea of utility, see Cifoletti G., "L'Utile de l'entendement et l'Utile de l'action", *Revue de Synthèse*, 2–3–4 (2001) 503–520.

ings, they constituted a first kernel of a community of *savants* working for the common good.

This paper focuses mainly on the biography of one academician, Jacques Besson, who authored the first *Theater of machines* in Europe and whose life and works offer rich material for the analysis of the contextual significance of the theatres of machines (and new inventions more broadly) during the economic, political and religious crisis of the late 16th century. Even if Bacon was undoubtedly an intellectual pioneer and his writings represented an element of rupture with the past, they might also be seen as the culmination of a long process that Huguenot authors had begun in France several decades earlier.

The Theaters of Machines in France – An Author and his Environment

The *Theater of machines*, one the few available sources for improving our scant knowledge and understanding of 16th-century technology and of its place in society, is a panorama of 'new inventions' which enjoyed great success, with bibliophiles, as well as *savants* and students.[6] Due to their structure, the almost exclusive emphasis on illustrations, and the description of the machines as 'new' and 'invented by the authors', it was generally assumed that their principal objective was the transmission of new technical knowledge. Therefore, historians who have worked on the theatres focus their attention almost exclusively on the machines themselves – the extent to which the images communicate information about the working of the machines, the likelihood that a reader, solely on the basis of the illustrations, could make a working model, and the actual novelty of the machines. While relevant, this exclusive interest in illustrations produced few insights into the true meaning of the theatres. Another misconception has been to assume that the authors were generally unknown technicians and inventors, who used the theatres as a vehicle to make their skills and inventions known to potential patrons and the public at large. Furthermore, their value has been mostly seen in aesthetic terms, much like today's 'coffee-table books', and historians

[6] On the "theatres of machines", see Dolza L. – Vérin H., "Les théâtres de machines de la Renaissance", *Revue d'Histoire moderne et contemporaine*, 51–52 (2004) 7–37 and the annexed bibliography.

have thus seen them as an a-temporal phenomenon that survived intact from the French religious wars to the Industrial Revolution.

On the contrary, an accurate interpretation of the theatres requires that they and their authors be contextualized, notably by studying their lives and networks. The life and work of Jacques Besson is exemplary in this regard. The hesitations that punctuate the slow working out of his theatre give us a clearer idea of the manifold and contradictory ambitions that inspired the different actors in the project. In fact, this literary genre bears witness to the vitality of both the mechanical arts and the book industry in the 16th century. His work was an original cultural phenomenon, which, in turn, provides a better understanding of the world that produced it. Besson was the author of *Théâtre des instruments mathématiques et mechaniques*, the first "theatre" ever published. Alex Keller and other scholars have unearthed a number of elements of his biography, including his religious faith, that shed a clearer light on the motivations of his and other similar books.[7] Of Italian origins, living in Switzerland, Besson built a strong relationship with Conrad Gesner, one of most well-known *savants* of his time, who enclosed Besson's research on medical oils in his famous

> De secretis remediis liber aut potuis thesaurus, Evonymo Gesnero Philiatro authore... accedit iam recens Iacobi Bessoni galli, de absoluta ratione olea et aquas e medicamentis simplicibus extrahendi Liber doctissimus, nunquam ante hac in lucem aeditus.[8]

[7] Droz E., "Jacques Besson ministre de Dieu et ingénieur" in *Les Chemins de l'hérésie* (Geneva: 1976) IV, 271–372; Hillard D., "Jacques Besson et son *Théâtre des instruments mathématique*", *Revue française d'histoire du livre* 48 (1979) 5–38; et *id.*, "Jacques Besson et son *Theatre des instruments mathematiques*, recherches complementaires", *Revue française d'histoire du livre* 50 (1981) 47–77; Keller A., "The missing years of Jacques Besson, inventor of machines, teacher of mathematics, distiller of oils and huguenot pastor", *Technology and Culture* 14 (1973) 28–39, et *id.*, "A Manuscript Version of Jacques Besson's book of Machines", in Hall B. – West D.C. (eds.), *On Pre-Modern Technology and Science, A volume of studies in Honor of Lynn White Jr.* (1976) 75–103.

[8] Gesner, one of the first scholars to insert detailed engravings in his books, devoted much time to the hyconographic apparatus. His well-known volumes *Historiae naturae* and *Opera botanica*, for which he designed and water-colored one thousand sketches of plants, are an eloquent presentation of evidence to his attention to detail and of the graphic perfection reached by the Swiss engravers of the time. Besson's text is published in Conrad Gesner, *Trésor de Evonime Philiatre, C. Gesner, des remedes secrets, livre physic, medical, alchymic* [...] (Lyon: 1555). Besson published it on his own few years later, *De absoluta ratione extrahendi olea et aquas e medicamentis simplicibus, accepta olim a quodam empirico, postea vero ab eodem Bessono locupletata et rationibus experimentique confirmata, liber* (Zurich: 1559).

Besson's connection to Gesner deserves special attention because of the importance Gesner assigned to classifications, something shared by Bacon decades later. As Rossi remarked, method, for Bacon, is a means of ordering and classifying natural reality. It is not a matter of chance that Bacon described it as a thread capable of guiding man through that forest and intricate labyrinth called Nature. The chief limitations of the Baconian method, continues Rossi, derive no doubt from the fact that Bacon had a very meager awareness of the function of hypotheses, abstractions, and mathematics in scientific research. But even this want of understanding, which led him to value "mechanics" like George Agricola over "theorists" like Copernicus and Galileo, is closely connected with the image of logic as the means of putting order into the natural "forest."

Like Gesner and his family, Besson was Protestant, a Calvinist. Details of his conversion are not known, although we know that he was married in Geneva by Calvin, then ill and approaching the end of his life. By 1559 Besson was a full-title member of the city and by 1561 he was on the list of bourgeois as: "mathématicien, gratuitement, en esgard des services qu'il a faict cy-devant et peult faire en ceste Republique, et aussi de ce qu'il enseigne en nostre Ville la science et artz mathematiques".[9]

Archival evidence shows the extent of Besson's networks and friendships. In August 1559, his first daughter, Sarah, saw the light and François Matthieu Beroald, teacher of Agrippa d'Aubigné and the Chair of Greek Literature in Geneva at the death of Thomas de Béze, was named her god-father. The friendship between the two men was to last: in the summer of 1568, as the persecution of the Huguenots intensified in France – more than one hundred people were killed and a temple destroyed – Beroald was captured and sent to jail. He escaped and took refuge at the court of Renée de France in Montargis, to which he invited Besson. While still in Geneva, Besson earned his life as a mathematic professor and "hydraulic engineer", professions in which he apparently excelled. In the spring of 1562, Besson's life changed suddenly. After the Poissy meetings in the summer of 1561, the reformed communities seemed to have conquered the degree of tolerance necessary for their growth. To satisfy the needs of the growing Protestant communities,

[9] *Livre des bourgeois*, quoted in Droz, *Les Chemins de l'hérésie*, 281.

many pastors – often hastily prepared – were sent to France. Despite repeated avowals of incompetence, Besson was sent as a minister to the domain of Olivier de Serres.

The period in Ardèche was a difficult one for Besson, as documented by Alex Keller and Hélène Verin.[10] Sharp disagreements with Olivier de Serres (author of the famous *théâtre d'agricolture*) and the difficulty encountered as an untrained minister led him to leave. Besson went first to Lyon, and then, once the Catholics re-conquered the city in 1562, to Orleans, where he was invited to offer his service to the benefit of the community as a "professor public" of mathematics. In 1567, during a period of relative calm following the peace of Amboise, Besson published his second work, *Le Cosmolabe*, in Paris.[11] The cover page refers to Besson as "professeur des dittes sciences mathematics en la ville d'Orléans" and includes the Protestant motto of those years: *ung dieu, ung roy, une loy*. 'Je vous present donc, Ma Dame, mon vray & principal exemplaire, illustré de figures propres & convenables pour eclarcir & rendre plus familiers les endroitz qui en ont de besoin.'[12]

In the *Cosmolabe* Besson described an instrument he claimed to have invented. Some passages shed light on Besson's attitude towards technology, for instance, the "préface de l'auteur" includes a statement explaining the religious importance he assigned to his work:

> vous me pourriez demander, en quoi ils ont tant failli. En ce premièrement, qu'ils ont usurpé le droit de leur Maistre qui est autant, que si le serviteur defroboit son seigneur, voire & d'avantage: d'autant qu'ils ont tasché de me priver non seulement de choses temporelles, mais encores des dons & grâces de l'esprit que Dieu m'a voulu donner & départir.[13]

For a Calvinist such as Besson, losing paternity over the instrument proved particularly damaging, since it kept him from displaying to the world his talents as an inventor, the 'dons & graces' that God had given him. To avoid the repetition of a similar intellectual theft in the

[10] On this period, see Dolza L. – Verin H., "Dal Livre al theatrum di Jacques Besson", in *Il Theatrum instrumentorum et machinarum di Jacques Besson* (Rome: 2002) 1–50 and the annexed bibliography.

[11] Jacques Besson, *Le Cosmolabe ou Instrument Universel concernant Toutes Observations qui se peuvent faire par les sciences mathematiques tant au ciel, en la terre comme la mer* (Paris: 1567).

[12] Ibid.: 'epistre a la Roine mere du roy'.

[13] Ibid.

future, the author peppers the entire work of numerous hints to his future theatre of 'more elevated and rare things':

> àse en attendant que par vostre liberalité j'aye recouvert le temps & les facultez de faire choses plus grandes & plus rares, & autant dignes de vostre grandeur, comme ie m'asseure quell'elles seroyent utiles & profitables pour toute la Republique

To make sure that his ideas were protected, the 1567 and 1569 editions included two pages entirely dedicated to a:

> Catalogue des meilleures plus subtiles et plus necessaires inventions: lesquelles par un long temps, grands frais, continuel labeur et peine, l'Auteur a trouvees & experimentées, tant és sciences mathematiques, qu'en plusieurs arts mechaniques.

A later passage in the book is useful to highlight the network of an "isolated and unknown technician". Besson could access the Royal Library, read the manuscripts, discuss them and be helped by Pierre de Mondoré, a famous mathematician and savant, in the translation from Greek. The book contains another interesting statement:

> Et pour ce que nous desiderans le profit & augmentation tout jours du bien public nous aous tant pris de peine qu'á l'ayde de mon bon seigneur & tresdocte maistre aux elementz d'Euclide, Monsieur de Mondoré, maistre de la Bibliotheque du Roy, qui nous a comunique ledit Pappus sur ce passage, que nous somes parvenuz á la connoissance de cette machine, de la quelle usa Archimedes au temps dudit Hieron.[14]

In 1552, Henry II had appointed de Mondoré director-responsible for acquisitions, cataloguing and studies of the collection of the King's library, Europe's richest collection of Greek manuscripts. The collection had been developed by several members of the royal family and had been augmented by several gifts and acquisitions. In 1544, this library consisted of more then 2,000 manuscripts, including hundreds of volumes on medicine, mathematics, military arts and technologies, and printed books. At the time of his appointment, de Mondoré was fifty years old, a member of the Great Council of the King, acquainted with the most influential people in Paris and reformed. In 1551, Mondoré had published a commentary on Euclid's elements to which Besson referred in the aforementioned passages. As Mondoré never made a mystery of his Protestant faith, once the religious wars started

[14] Ibid., 242–243.

anew in 1567 he was forced to flee, first to Orleans, his home city and a safe haven for Protestant refugees, and then to Sancerre, where he died in 1570.

The preface of the 1567 *Cosmolabe* includes another passage that strangely does not seem to have captured the attention of scholars: 'combien qu'il y ait environ douze ou treize ans, mes bénévoles e bien aimez auditeurs, que je lisais en ceste célèbre Académie de Paris, les Mathématiques en latin.'[15]

Little is known on academic activities in Paris during the second half of the sixteenth century. The only Academy to have been the object of detailed studies is the Pléiade, founded by Jean Antoine de Baif. Members of the academy met regularly at the Louvre, were interested chiefly in poetry and music, and played an important role in the defence of the French language and in the translation of the classics. The academy was not interested in scientific or technical activities and, indeed, Besson is not included in the list of its members.

Information is provided by another Parisian author, Jacques Gohory (1520–1576), well known to scholars of Paracelsus and Machiavelli – a fact which, surprisingly, has not attracted the attention of historians of science, despite the fact that Gohory founded what may have been the first Parisian scientific academy. Following the family tradition, he began a career as a lawyer or diplomat, even though he soon realised that his true interests were elsewhere. He began to devote himself to "de son gré à la contemplation de Nature pour negotier avec elle seule hors des troubles, vices et confusions du monde", in order to discover "de beaux secrets à grand travail et dépense pour l'usage de l'homme". Gohory never formally gave up his position as a lawyer at the Parliamentary Court in Paris, but devoted all this time to the study of literature, music, philosophy, medicine and the occult. In keeping with the *Envie, d'envie, en vie* motto that accompanied all his works, he translated numerous texts: *Hyperomachia Poliphili*, as well as writings of Amadis de Gaule, Macchiavelli, Titus Livius and Paracelsus. In 1567, Gohory published his *Compendium*, a book devoted to the philosophy and medical theories of Paracelsus and which ignited a great deal of

[15] Besson, *Le Cosmolabe*, fol. A3, Preface.

scholarly controversy.[16] In this volume, published by the same publisher of Besson's *Cosmolabe*, he expressed his unconditional approval of the analogy of the micro and macrocosm and stressed the importance of the cabal and of numbers.

In 1571, Gohory also decided to establish an academy, the *Lycium philosophal*, for the study of alchemy, botany, medicine, mechanics and the art of divination. The *Lycium philosophal* met periodically at the home of Gohory in Faubourg Saint Marceau, which had a specially-designed space to conduct scientific experiments. Very little archival evidence remains of the meetings held in Gohory's home, with the exception of a few references in his books and an engraving depicting Ambroise Paré in a park dominated by a hill on which stands a windmill, as in Faubourg Saint Marceau. The *Lycium philosophal* takes its name from another of Gohory's works, *Instruction sur l'herbe petum*, which is the richest source of autobiographical information about the author. This book, published in 1572, again by the Parisian editor of one of Besson's works, featured several woodcuts. In *Instruction*, Gohory describes his garden, the rare plants which he cultivated, the climatic conditions in which they grew, his sundial, the fountains, the labyrinths, and pavilions where chemical experiments were carried out, and, finally, the friends and visitors who shared his interests. One of them was Jacques Besson, the "mathematician". In 1567, in *Cosmolabe*, Besson wrote that he had been a member of a Parisian academy for 12 years. As Gohory founded his academy first in 1571, Besson clearly must have been referring to a different one. Unfortunately, we do not know more than that, although Ramus, the previous year also refers to the contacts he was having with all the members of the *academia parisiensi* interested in mechanics.[17] Still, which academy he was referring to remains unknown.

Empiricism and Utility

That Paris could be home to two academies, Gohory's and the one mentioned by Ramus, is not surprising as the city was, alongside Lyon,

[16] See Kahn D., "Le paracelsisme de Jacques Gohory", in *Paracelse et les siens, Aries* 19 (1995) 65–153. On Gohory, see Hannaway O., "Gohory", *Dictionary of Scientific Biography* vol. 5, 447–448.

[17] Ramo, *Actio Regia mathematicae professionis cathedra, habita in Senatu 3 id martis anno 1566.*

the main cultural centre in France. Among the books that Bacon could have read in Paris, the writings by Palissy, Ramus and Peletier stand out, as does the work of Agricola.[18] The Palissy's *Discours abmirables* was first presented in public lectures (which Bacon might have attended) and published in 1580.[19] It is presented as a dialogue in which practice always prevails over against theory. In the preface, in order to silence those who assert that no one has the right to speak of nature without prior knowledge of Latin philosophers, Palissy argued that it is practice that generates theory. Practice needs the use of compass, ruler, numbers, measures, intelligences, and therefore ought not to be considered subordinate to theory. In fact, Palissy did not reject theory but aspired to build, as did Besson, a strong link between theory and practice for the sake of knowledge and utility.

The same interest in the relationship between theory and practice was shared by the humanist and mathematician Jacques Peletier du Mans. In 1573, a few years after Jean Bodin had developed a general theory of history to demonstrate that the discoveries and inventions of the moderns are not inferior to those of the ancients, Peletier, in his *De l'usage de geometrie*, argued that theory and practice were both necessary to understand a craft.[20] Peletier, like Besson, believed that man's role was to discover what was hidden by the secrets of nature.

Another key figure of Parisian cultural life was Ramus, a Calvinist, who was calling for a reform of the University of Paris to make its curriculum more relevant to practical life.[21] The influence of Ramus on Bacon has been studied, and Rossi remarked that, concerning method, Bacon was much closer than he realized to the conceptions of dialectic entertained by Ramus or Melanchthon when they conceived it as the means for the orderly disposition of ideas, establishing order in a reality which presents

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[18] On Parisians books and the meaning of utility, see Cifoletti, "L'Utile de l'entendement", and Heller H., *Labour, science and technology in France, 1500–1620* (Cambridge: 1996).

[19] Bernard Palissy, *Les Œuvres*, publiées d'après les textes originaux avec une notice historique et bibliographique et une table analytique par Anatole France (Paris: 1880; Geneva: 1969) 165–68.

[20] Jacques Peletier, *De l'usage de la geometrie* (Paris: 1573).

[21] See also Hooykaas R., *Humanism, science et réforme: Pierre de la Ramée, 1515–1572* (Leiden: 1958), Sharrat P., "Peter Ramus and the Reform of the University: the divorce of Philosophy and Eloquence", in Sharrat P. (ed.), *French Renaissance Studies, 1540–70, Humanism and the Encyclopedia* (Edinburgh: 1976) 4–20.

itself as something chaotic.[22] The Baconian conception of scientific method, despite all that is distinctive about it, still moves on the terrain of the Ramist definition of *dispositio.* Furthermore, in *Remonstrance au Conseil Privé*, in 1567, he even suggested abolishing the distinction between liberal and mechanicals arts, arguing than anyone who practices must also make use of geometry. Ramus was convinced that mathematics formed the foundation of mechanical inventions, a point that Besson was also trying to make. A few years later, in 1569, while still living in Orléans, Besson published with Pierre Trepparel, who had adopted the motto *in silentio fortitudo* and was to be killed in the Saint Bartholomew's massacre, and Eloy Gibier, his *L'art et science de trouver les eaux et fontaines*, an important book to understand how to relate theory and practice.[23]

Despite the title, this book is not at all a cabalistic or hermetic volume. Here, Besson suggests a method to find subterranean sources of water, using theology as mediator:

> Si ie tien donc ici l'ordre plus d'un Mathematicien que d'un Physicien ou Theologien en choses, di ie, qui tiennent de l'une & de l'autre profession, & ausquelles ne suis suffisamment exercité, ie prie un chacun m'excuser, protestant qu'en cela ie ne tasche que d'extraire les premieres causes, pour mieux parvenir aux regles & effects de verité, ne voulant cependant ni desiderant imaginer chose qui n'accorde au bon ordre que Dieu a voulu declarer aux hommes par la creation du monde: entendu qu'on doit permettre á tous ceux qui enseignent choses obscures & comodes, tout ce qu'ils cognoissent á leur fin estre le plus expedient, sans regarder á ce qui est commun.[24]

The title of the book underscores the contrast between Besson's "science" and the "common" empirical method employed by farmers and architects. Besson blames empirical methods as useless and extravagant expenses, and promises to eliminate such problems through a melange of empiricism and the theory of the first cause, of practice and theory, of theology and physics. According to him, pure theory and simple

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[22] Rossi, *Francis Bacon*; Howell W.S., *Logic and Rhetoric in England: 1500–1700* (Princeton: 1956); and Walton C., "Ramus and Bacon on Methods", *Journal of the History of Philosophy* 9 (1971) 289–302.

[23] Jacques Besson, *Art et science de trouver les eaux et fontaines cacheés soubs terre, autrement que par les moyen vulgaire des Agriculteurs & Architectes, par Iaques Besson, Dauphinois, Mathematicien.* (Orléans: 1569), avec privilege du Roy pour dix ans.

[24] Ibid., 4–5.

practice, individually, are sterile. It is only the adoption of his method, with the mediation of theology, that leads to the discover of solutions and creates definite results.

Again, *L'art et science de trouver* is a rich source of information on the authors' life and thoughts. In the preface, Besson insists in presenting himself as a mathematician and, in remarkable rhetoric, pretends to be a professor of mathematics at Orleans:

> & honorez ceux qui en sont profession come de ce en general vous rendent tesmoinage toud les Docteurs Regen & Escholier de l'Université d'Orleans, qui par vostre prudence & amitie naturelle que que portez á la science, avez maintenus en paix & repos, & moy en particulier, qui vous en rend graces immortelles.

The protestant *milieu* supports the dream of Besson: the publication of not a "theatre" but "the first book on mechanical devise". In its preface Besson writes: 'Ie travaille aussi à present, pour dedier à sa Maieste, á un ample livre, distribué en plusieurs inventions nouvelles d'instrumens & machine utiles.'

Galiot du Pré II, the Besson's Parisian publisher, presented the author to François de Montmorency, *liutenant* of the King and husband of a natural daughter of Henry the II.

> Non content de m'avoir conservé, m'avvez moyenné la cognoissance & faveur de mon Roy, de la Royne sa mere, e de Monsieur, faisant entédre à leurs Maiestez les oeuvres des choses plus rares & exquises des sciences Mathematiques, lesquelles j'ai tasché dépouis vingtcinq ans ença à elabourer[25]

Besson dedicated to Galiot the second version of the *Art et moyen parfaict de tirer huyles et eaux*,[26] which Besson revised and expanded while temporarily living in Montargis.[27] Montargis is an important place for scholars of French history and French Protestantism. This castle, owned by the duchess Renée, daughter of François I, was a famous shelter for the Protestants fleeing from war. One of them was Androuet du Cerceau,

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[25] Ibid.

[26] Ibid.: 'reçeu d'un certain empirique qu'on estimoit alleman & depuis confirmé par Raisons e experiences'.

[27] Archives National, Paris, Minutier Central, Etude LXXIII, liasse 76, mardi 12 décembre 1570.

one of the most important engravers and architects of his time, who participated in the publication of Besson's books:

> Rendez finalement graces à plusieur sçauans, pourtrayeurs & sculpteurs de ce Royaume de France, qui de leurs mains & industrie, ont entreprins de graver (à ma requeste) en tables d'airein, toutes ces presentes inventions: & entre autres donnez louange à maistre Iacques Androuet, dict du Cerceau, Architecte du Roy & de madame la Duchesse de Ferrare.[28]

All the engravings, except four, were likely made in his *atelier*. The others were by the hands of Rene Boyvin, an artist who had already depicted Calvin, Melanthon and Luther. A friend of Gohory, with whom he collaborated on the publication of the *Toison d'Or*, Boyvin's faith was so well-known that after spending some months in various prisons, he was forced to flee Paris. In 1572, Besson, who already had obtained a ten year privilege for his book, was given money by the King:

> A Jaques Besson, ingénieur et matematicien, dud. Sgr. la somme de 560 l.t. dont led. sgr. luy a faict don en consideration de ses services et pour le recompenser d'ung livre des angins et instrumens mathematiques qu'il a presenté et dedié a sadicte majesté.[29]

At that stage, the book must not yet have been in print, since Jean de l'Orme in the French edition of *Art et Moyen parfaict de tirer huyles ey eaux* published by Galiot du Pré at the end of 1572, but dated 1573, could write:

> pourtant l'experience
> de ses inventions monstre mieux sa Science,
> Tesmoin son Cosmolab'nay tout nouvellement,
>
> et si fera encor'qu'en bref tu pourras veoir
> mille braves engins, preuve de son sçavoir,
> donq'estime sans plus, envers toy sa largesse,
>
> qui t'enseign pour rien ses distillations
> au lieu qu'il amassoit des autres nations,
> pour leur monstrer cet Art, une grosse richesse.[30]

Sometime between 1573 and 1578, when Besson presumably died, a few and now rare copies of the book were published with the title:

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[28] Besson, *Livre, s.d.* epistre.

[29] B.N.P., Paris, Manuscripts, *Fonds Clairambault*, vol. 233, 1572.

[30] Jacques Besson, *L'art e la science* (Paris: 1573). Only in this edition we can find this poem, written by Jean de l'Orme. See Droz, *Les Chemins de l'hérésie*, 325–327.

"Livre Premier des Instruments Mathematiques, et mechaniques, servants a l'intelligence de plusieurs choses difficiles, & necessaire á toutes Republiques, inventés (entre autes) avec infinis labeurs par Iaques Besson, Dalphinois, professeur & ingenieux es sciences mathematiques".[31] "L'infinis labours", the machines invented or understood by the author, as mentioned before, were protected by a "privilege", one of the earliest of its type in France (the only older one is that of Abel Fullon) as it combined elements of copyright and patent. Ironically, it did not prevent an Englishman, Cyprian Lucar, from plagiarizing Besson for Elizabethan consumption across the Channel.

Besson's real success was posthumous. In 1578, Claude Juge published in Geneva, but with a French editor, Besson's engravings with their explications by François Beroald de Verville:

> mon seigneur, cil qui void les engins de Besson
> ne pouvant pas sonder la science secrete
> de cest art tant subtil, Besson mesme il regrette
> pour de tels instrumens luy faire une lecon.
> mais pius que Beroald a trouvé la facon
> d'expliquer ces engins, il n'y a point de perte
> en la mort de Besson sa vie est recouverte:
> Beroald maintenant nous met hors de soupson.
> De si vives raisons ces pourtraicts il explique
> par l'art industrieux de la Mathematique
> que de tous ses engins on comprend les effects.
> Puis il a son labeur sacré á vostre gloire,
> Digne entre les Francois de l'heureuse memoire
> que merite l'effect de ces rares pourtraicts.[32]

The posthumous "theatre" lost some of Besson's aims, but one has been emphasized in the ode to Besson's memory "aux amateur de ces Sciences":

> ou avec leur industrie
> faire bien à leur patrie,
> comme bien fasoit nostre auteur,
> qui suant sous son aleine

[31] Saint Genevieve Library, Paris, Res.V. 179, Inv. 218.

[32] Jacques Besson, *Théâtre des instruments mathématiques et méchaniques* (Lyon: 1578), preface. On this edition, and on Besson in general, see Dolza L. – Vérin H., "Dal livre al Theatrum di Jacques Besson", in *Il Theatrum Instrumentorum et machinarum di Jacques Besson* (Rome: 2001) 1–49.

n'espargba jamais sa peine,
tant qu'es os il eut vigueur.
Donques d'un oeil debonnaire
vueillez de coeur accueil faire
accoeil a cet *theatre divin*.[33]

The Protestant exodus, the purchase of books and manuscripts and the growing interest of the English government for technology combined to transfer this body of knowledge to the other side of the Channel, where Bacon was soon to write his texts. Besson did not ever travel to England, but his work did – both in printed and hand-written form. The only surviving manuscript of Besson's theatre is, at least from the XVIII century, in England.[34]

Conclusions

With few exceptions, most historians consider Renaissance technology before Galileo and Bacon as a binary system. On the one hand, stand craftsmen, engineers and technicians who operated without precise rules, devoid of any knowledge other than that of their jobs' methods and processes. On the other, stand philosophers, who were becoming increasingly interested in explaining natural phenomena, but had no interest in applying their knowledge for practical purposes. According to the literature, this tension broke down between the end of the 16th century and the beginning of the 17th century, when an enlightened elite became aware of the role the knowledge of nature could play in controlling its forces and using them to generate economic wealth. The crucial events highlighted in this respect were Galileo's visit to the Venice Arsenal and the writings of Bacon and Descartes. Following those seminal events, the majority of scholars in Europe tried to ally technology and science, aware that applying science to productive processes would be the key to the future of civilization.

Many such beliefs are challenged by the in-depth study of *Theatre of machines*. What such studies show is that at the time of Bacon's stay in France, technology, far from being the exclusive domain of unknown and obscure technicians, were also of interest to well-established scholars

[33] Besson, *Théâtre*, "aux amateurs de ces Sciences, ode".
[34] The manuscript, discovered by Keller, is at the British Library. In the first page is written "ex dono domini Jacobi de Saint Rémy".

who were assigning technology a religious meaning. As in Puritan England some decades later, the majority of the authors of theatres of machines harbored strong religious beliefs that deeply shaped their lives and works. One of the most interesting aspect of the prefaces to the Theatres is the stress they almost always lay on theological justifications for technology. The mechanical arts are God's gift to mankind and offer some compensation for the losses suffered at the time of the Fall. Furthermore, just as God has ordered all things according to measure, weight, and number, so too the mechanical technologist arranges his creations according to the same principles.

As mentioned by some scholars, many of these relatively conventional statements derived from scholastic thought and some may have been rhetorical strategies for 16th-century technologists to win a recognized place in the intellectual world by linking their activities to contemporary "high culture". Technology had become, at least in the minds of its articulate practitioners, an activity that deserved public recognition, rooted in the oldest of sciences – mathematics – and was justified by theological considerations. But this position can also be seen as an attempt by religious groups to link technology and its utility to their aims. Either way, the attitude toward technology we usually associate with the seventeenth century has its roots also in the technical writings of the preceding century.

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FRANCIS BACON'S *SCIENTIA OPERATIVA*, THE TRADITION OF THE WORKSHOPS, AND THE SECRETS OF NATURE

Jürgen Klein

> Moreover the works already known are due to chance and experiment rather than to sciences; for the sciences we now possess are merely systems for the nice ordering and setting forth of things already invented; not methods of invention or directions for new works.
>
> Francis Bacon, *Novum Organum*, I. viii[1]

Introduction

Bertolt Brecht's scene in his "Schauspiel" *Leben des Galilei*, in which the mathematician and philosopher Cremonini refuses to look through Galileo's telescope, because he prefers to draw information concerning the reality of nature merely from reading Aristotle, has always been used as a metaphorical dramatization of the clash between the traditional and the early modern world picture.[2]

Is it possible, asked Francis Bacon and Galileo that we can grasp the workings of nature on the grounds of studying written authorities without any reference to the analysis of natural processes by use of our senses and by experimental methods of investigation? In his *Novum Organum* Bacon wrote:

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[1] Francis Bacon, *Works*, ed. Spedding, Ellis, Heath (London: 1901) vol. IV, 48.

[2] Brecht B., *Leben des Galilei* (Frankfurt am Main: 1977) 40–50, especially 48: '*Der Mathematiker* Lieber Galilei, ich pflege mitunter, so altmodisch es Ihnen erscheinen mag, den Aristoteles zu lesen und kann Sie dessen versichern, daß ich meinen Augen traue.
Galilei Ich bin es gewohnt, die Herren aller Fakultäten sämtlichen Fakten gegenüber die Augen schließen zu sehen und so zu tun, als sei nichts geschehen. Ich zeige meine Notierungen, und man lächelt, ich stelle mein Fernrohr zur Verfügung, daß man sich überzeugen kann, und man zitiert Aristoteles. Der Mann hatte kein Fernrohr.' Cf. Lange F.A., *Geschichte des Materialismus*, ed. H. Cohen (Leipzig: [6]1898) vol. 1, 183.

> In order to penetrate into the inner and further recesses of nature, it is necessary that both notions and axioms be derived from things by a more sure and guarded way; and that a method of intellectual operation be introduced altogether better and more certain.[3]

The 17th-century scientific revolution presupposes active experiments instead of uncritical passive observation. Galileo comments on his unexpected results by observing:

> how conclusions that are true may seem improbable at a first glance, and yet when only some small thing is pointed out, they cast off their concealing cloaks [le vesti che le occultavano] and, thus naked and simple, gladly show off their secrets.[4]

It is a truism that Bacon's famous criticism of purely speculative philosophy, traditional metaphysics, and natural philosophy from Plato and Aristotle to his own time[5] is closely connected to his revival of materialism,[6] his emphasis on empirical research, and on his praise of artisans and workshops. It has to be emphasized that Bacon's idea of empirical science and his conception of technology cannot be seen as separate unities, but as a complex formation based on interdependence.[7]

1. *Bacon and the Artisans*

Already in his earliest writings Francis Bacon contrasted the inefficiency of science – especially in antiquity and within the epoch of scholasticism – with the achievements of contemporary artisans. For Bacon 'Historie Mechanical' is 'the most radicall, and fundamentall towards Naturall Philosophie', since it does not care for vain speculations, but for the products of artisans in their workshops. HISTORIE MECHANICAL thus is fundamental to natural philosophy, because it

[3] Bacon, *Works* IV (1901) 50.

[4] Galileo Galilei, *Two New Sciences*, trans. Stillman Drake (Madison: 1974) 14; Cf. on occult qualities in early modern science: Hutchison K., "What Happened to Occult Qualities in the Scientific Revolution?", in Dear P. (ed.), *The Scientific Enterprise in Early Modern Europe* (Chicago-London: 1997) 86–106.

[5] Cf. Klein J., "Bacon's Quarrel with the Aristotelians", *Zeitsprünge* 7 (2003) 10–31.

[6] Cf. Bacon, *Works* V (1889) 459–500 (*De principiis atque originibus, secundum fabulas Cupidinis et Coeli*).

[7] Concerning the general question of occidental technology see: Mumford L., *The Myth of the Machine* (New York: 1966); Moscovici S., *Essai sur l'histoire humain de la nature* (Paris: 1968; 1977).

> Shall bee operatiue to the endowment, and benefit of Mans life: for it will not onely minister and suggest for the present, Many ingenious practises in all trades, by a connexion and transferring of the obseruation of one Arte, to the vse of another, when the experiences of seuerall misteries shall fall vnder the consideration of one mans simile: But furder, it will giue a more true, and reall illumination concerning Causes and Axiomes, then is hitherto attained. For like as a Mans disposition is neuer well knowen, till hee be crossed, nor *Proteus* euer chaunged shapes, till hee was straightened and held fast: so the passages and variations of Nature cannot appeare so fully in the libertie of Nature, as in the trialls and vexations of Art.[8]

1.1 *The Tradition of the Workshops*

The tradition of the workshops was very strong in Renaissance Italy. Here the acceptance of the practical arts, which implied technical aspects, cannot be denied. We have to think among other occupations of weaving, spinning, pottery, and glass-making but also of painting, sculpture-making, architecture, and tool- or instrument-making. Together with the revival of mathematics and physics, the arts of ballistics and of fortification became prominent and thus engineering in general, which also covered mining and ship-building.[9]

Famous Italian artisans were Filippo Brunelleschi, Lorenzo Ghiberti, Leone Battista Alberti, Nicolo Tartaglia, and – last not least – Leonardo da Vinci.[10] In Florence the artisans were members of lower rank in the guild of *Medici e Speciali*. The practical artisans tried to solve technical problems on the ground of practical solutions as we know from ship-wrights, architects, and instrument makers. They could claim to represent the *uomo universale*, but their intellectual independence was not necessarily based on vast scholarship but more so on technical know how. That does not mean that exceptions were lacking, since quite a few individuals partook in knowledge and competence of both strands – book learning *and* practical competence. The important factor for Bacon's estimation of the artisans remains in this curiosity for the real world, evident in the endeavours and achievements of inquisitive and

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[8] Francis Bacon, *The Oxford Francis Bacon*, vol. IV, ed. K. Michael (Oxford: 2000) 65. Cf. Bacon F., *Works* VII (1892) 498 seqq.

[9] See: Cipolla C.M., *Vele e cannoni* (Bologna: 1983).

[10] See: Vasoli C., "Leonardo da Vinci: Der Künstler als Wissenschaftler und Techniker", in Fehrenbach F. (ed.), *Leonardo da Vinci. Natur im Übergang* (Munich: 2002) 19–36.

experimenting minds. Enthusiasm for technical know how must be seen as a competence advantage for the artisans, and explicitly that was highly cherished by Francis Bacon. Nevertheless it took a long time until the collaboration between the artisans, their revived techniques of antiquity, and the new methods of *scientia operativa* could establish a modern theory – practice – pattern. The artisans contributed substantially towards the progress of knowledge and technical versatility in the early modern period, but their type did not correspond automatically and right from the beginning to Bacon's *new man of science*[11] and his idea of *the maker's knowledge*.[12]

Before Bacon's *man of science* was shaped as the new prototype of the researcher or natural philosopher, the artisan held practical aims as prevalent without constituting a sufficient – thus a more than basic – scientific theory, even if he did not abstain from theoretical reflection altogether.[13] Theory traditionally had remained close to the specific discipline and thus no general theory of science and technology had come in sight. Even the theory of mechanics remained within the framework of Aristotelian natural philosophy until Galileo revolutionized physics.[14]

Leonardo can be taken as a representative of the tradition of the workshops. He concentrated on technical constructions, based on Archimedes' statics, but in dynamics Leonardo did not transcend the limits of Aristotle's theory of motion.[15] Though Leonardo demanded that the sciences also include the tasks of the artisan, since intellectual effort and manual versatility cannot be separated, he was not able to

[11] On Bacon's new man of science see: Prior M.E., "Bacon's Man of Science", *Journal of the History of Ideas* 15 (1954) 348–370 and: Gaukroger S., *Francis Bacon and the Transformation of Early Modern Philosophy* (Cambridge: 2001) 101–131.

[12] See: Pérez-Ramos A., "Bacon's forms and the maker's knowledge tradition", in *The Cambridge Companion to Bacon*, ed. M. Peltonen (Cambridge: 1996) 99–120; Idem, *Francis Bacon's Idea of Science and the Maker's Knowledge* (Oxford: 1988).

[13] Cf. Olschki L., *Bildung und Wissenschaft im Zeitalter der Renaissance in Italien* (Leipzig, Firenze, Roma-Genéva: 1922) 273.

[14] On Galileo's revolution in physics cf. Mittelstrass J., *Neuzeit und Aufklärung* (Berlin-New York: 1970); Feyerabend P.K., *Against Method* (New York: 1975); Drake S., *Galileo* (Oxford: 1980).

[15] Cf. Mittelstrass J., *Neuzeit und Aufklärung* 178–179. For Aristotle's theory of motion cf. Wieland W., *Die aristotelische Physik* (Göttingen: 1970) 110–140.

turn the argument round by giving an outline to a valid theory of science, which could make the two ends meet.[16]

1.2 *Bacon on Traditional Philosophy and on Artisans*

Both Bacon and the Italian artisans criticized pure book knowledge in natural philosophy, because it lacked empirical warrants or it even neglected the assumption that the (often hidden) workings of nature have to be accounted for by rational explanation based on factual investigation. Of course we have to take into consideration that there is a difference in respect of the criticism of authorities between Bacon and the artisans. When the artisans repudiated the scholastic tradition, they did not automatically succeed in evading sophisms and they did not rule out the construction of connections, which did not and could not exist. Bacon knew that the artisans because of their skill, experience, and practical knowledge of matters and things were nearer to the message in the Book of Nature than the scholastics. From this perspective Charles Webster's remark is illuminating:

> Such figures as Agricola, Palissy and Stevin were willing to bridge the gulf between the scholar and the craftsman; they had exhibited the enormous potentialities of literate technology. On the other hand neither the scholastic philosopher nor their critics could satisfy Bacon that they were sufficiently aware of the need to relate natural philosophy to its natural roots in experience.[17]

Sticking to concepts like quality, substance, form, accidence, essence, and potency proved to be impediments for the development of modern science, since this terminology was bound to Aristotle's highly speculative and dogmatic natural philosophy.[18] The same is true for those late Renaissance scholars, who remained within the limitations of the

[16] Cf. Bernal J.D., *Die Wissenschaft in der Geschichte* (Berlin: 1961) 273; On the necessity to combine experiment and theory within science see: Böhme G. – van den Daele W. – Krohn W., *Experimentelle Philosophie* (Frankfurt am Main: 1977) 63–115.

[17] Webster Ch., *The Great Instauration. Science, Medicine and Reform 1626–1660* (London: 1975) 337–338.

[18] 'Solange Cardan und die Telesianer von Qualität, Substanz, Form, Akzidenz, Wesen, Potenz und den Kombinationen dieser und anderer Begriffe reden und diskutieren, solange die Richtung teleologisch, die Betrachtung animistisch, die Dialektik deduktiv-syllogistisch ist, gehören sie alle der scholastischen Überlieferung an.' Olschki, *Bildung und Wissenschaft*, 18.

Aristotelian framework. In contrast to those scholars Bacon questioned the speculative combinations of physical world explanations and conceptual networks of a pure a priori character as well as concerning ancient as in relation to contemporary natural philosophy:

> wee may note in these Sciences, which holde so much of imagination and Beliefe, as this degenerate Naturall Magicke, Alchimie, Astrologie, and the like, that in their propositions, the description of the meanes, is euer more monstrous, then the pretence or ende. For it is a thing more probable, that he that knoweth well the Natures of *Waight*, of *Colour*, of *Pliant*, and *fragile* in respect of the hammer, of *volatile* and *fixed* in respect of the fire, and the rest, may superinduce vpon some Mettall the Nature, and the forme of Gold by such *Mechanique* as longeth to the production of the Natures afore rehearsed, then that some graynes of the Medicine proiected, should in a fewe moments of time, turne a Sea of Quick-silver or other Materiall into Gold.[19]

It is obvious that Bacon prefers the competence of the artisan to the promises of the pseudo-scientist. Bacon's attitude to the mechanical arts, however, was not uncritical and the same must be assumed for his estimation of the non-mechanical arts, which began to become prominent after 1540. According to Thomas S. Kuhn these arts were presumably encouraged by Paracelsian outlooks.[20] It is important to underline here that Francis Bacon has been influenced by two artisans,[21] who had become famous for their technical inventions and for their emphasis on the empirical world.

2. *Bernard Palissy (1510–1590)*[22]

Bernard Palissy, a French potter, experimentalist, and artisan, had become famous for his artful and colourful faiences. His dishes were sculptured relief like with plants and animals in a style, which gave the impression of living creatures. This effect can be explained by the fact

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[19] Bacon, *The Oxford Francis Bacon* vol. IV, 89.

[20] Cf. Kuhn Th. S., "Mathematical vs. Experimental Traditions in the Development of Physical Science", *The Journal of Interdisciplinary History* 7 (1976) 1–31.

[21] Cf. Rossi P., *Francis Bacon. From Magic to Science* (London: 1968) 9–11.

[22] On Palissy cf. Rossi P., *Francis Bacon*; Farrington B., *The Philosophy of Francis Bacon. An Essay on its Development from 1603 to 1609. With New Translations of Fundamental Texts* (Liverpool: 1964); Shearman J., *Mannerism* (Harmondsworth: 1973) 127–130 and 156–158; Rossi P., *La Nascita Della Scienza Moderna in Europa* (Rom-Bari: 1997) Chap. 3; Shell H.R., "Casting Life, Recasting Experience: Bernard Palissy's Occupation between Maker and Nature", *Configurations* 12 (2004) 1–40.

that Palissy used living plants and animals for making the moulds he needed in the process of producing his ceramic creations.[23] According to Paolo Rossi Bacon read Agricola and was inspired by Palissy.[24] The reason for Bacon's interest in Palissy must have been that the latter was a great experimenter, who made notes on his efforts and published in 1553 a book on the art of pottery.[25] Combining 'the imaginative fecundity of an artist with the resource of a practical technologist'[26] enabled Palissy to prove his mastery in garden practice, which included the building of grottoes, for which glazed ceramics were used. One of his famous grottoes was erected for the Duc de Montmorency in the garden of the Tuileries about 1570. It is important that Palissy claimed 'the greatest realism in details such as fish-scales and leaf-veins.'[27]

In 1580 Palissy published his major work *Discours admirables de la nature des eaux et fontaines*, in which he described his experiments to produce artistic ceramics, but he included discussions on chemical, geological, mineralogical and general technical subject matters. Palissy who was a great artisan and a man of practice ridiculed the scholastics and the alchemists because their book knowledge was not complemented by experiences with nature and with experiments proper. Palissy must have assumed that there do exist secret powers in nature, but he obviously did not accept the connection between invisibility and non intelligibility. Even if one cannot know causes one has to study nature so scrupulously that methods are developed, which establish the possibility of repeating the effects of nature under experimental conditions.

Markku Peltonen has suggested that Francis Bacon might have met Palissy in Paris, when he stayed there between 1576 and 1579 as an assistant to the English ambassador in France, Sir Amias Paulet.

> There has been some speculation of the possible impact on his intellectual development of the French courtly *académie* and of Bernard Palissy (...) whose public lectures on agriculture, mineralogy, and geology Bacon could have attended.[28]

[23] See: Shell H., "Casting Life", ibid.
[24] See: Rossi P., *Francis Bacon*.
[25] The book's title is: *Recepte veritable par laquelle tous les homes pourrout accroître leurs trésors*. Cf. Ludwig K.-H. – Schmidtchen V. (eds.), *Metalle und Macht* (*Propyläen Technikgeschichte*), ed. K. Wolfgang, Band 2 (Berlin: 1997) 458–459.
[26] Shearman J., *Mannerism* 127.
[27] Shearman J., *Mannerism*, 130.
[28] Peltonen, *The Cambridge Companion to Bacon* 3. Cf. Farrington B., *The Philosophy of F. Bacon* 33.

In his *Discours Admirables* Palissy had written:

> I can assure you, dear reader, that in a few hours, in the very first day, you will learn more natural philosophy from the objects displayed in this museum[29] than you could in fifty years devoted to the study of the theories of the ancient philosophers.[30]

Palissy's outlook must have been fascinating for Bacon, who already very early had anticipated the possibility of the rise of the sciences in an 'alliance between intellectual and manual work, between head and hand.'[31] It is important to mention that Palissy owned books by Vitruvius, Paracelsus, and Cardano, which might have influenced him, though philosophy for him converges with the 'art of observing'.[32] Palissy's statement from *Discours admirables* given above was introduced by another interesting remark:

> How can a man understand and discuss the workings of nature if he has not read Latin books of the Philosophers? So might it be said of me, for I prove by experiments that the theories of many philosophers are fallacious in many ways, even the most famous and ancient; and this can be seen and understood in less than two hours, by anyone who will take the trouble to come to my laboratory where he will see some wonderful things set up as examples and proofs of my writings, arranged by order and by degree, with labels attached so that everyone can learn for himself.[33]

It does not seem unlikely that Bacon's unpublished *Redargutio philosophicarum* or *The Refutation of Philosophies*, written in 1608, refers to Palissy. It presents 'a discourse by an Unknown Stranger to a Parisian audience

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[29] Palissy owned a museum of natural objects. The 16th century has quite a few examples of museums or *Kuriositätenkabinette*, Fe Ulisse Aldovrandi's museum in Bologna or that of Ole Worm in Copenhagen. See: ed. A. Grote, *Macrocosmos in Microcosmo. Die Welt in der Stube. Zur Geschichte des Sammelns 1450–1800* (Opladen: 1994); Cf. Bennet J. – Mandelbrote S. (eds.), *The Garden, the Ark, the Tower, the Temple. Biblical metaphors of knowledge in early modern Europe* (Oxford: 1998) 73–102; Klein J., "Renaissance Sensualism Methodized: Francis Bacon, *Wunderkammern*, Natural History, and the Beginnings of Systematic Empiricism", in Houswitschka C. – Knapp G. – Müller A. (eds.), *Anglistentag 2005. Proceedings* (Trier: 2006) 183–205.

[30] Quoted after: Farrington B., *The Philosophy of F. Bacon* 33.

[31] Farrington B., *The Philosophy of F. Bacon* 32.

[32] Cf. Rossi P., *Francis Bacon* 9. 'The French translation of Cardano's *De Subtilitate* (1556) influenced the vernacular works of Ambroise Paré and the potter Bernard Palissy.' Daston L. – Park K., *Wonders and the Order of Nature 1150–1750* (New York: 2001) 171.

[33] Palissy, *Discours admirables* (*Les Oeuvres de Bernard Palissy*) (Paris: 1880) 166, quoted from: Rossi P., *Francis Bacon* 8–9.

of men.'[34] Like Farrington we could imagine that Bacon chose a camouflage of that sort for himself. But we also could assume that Bacon transformed Palissy into this 'Unknown Stranger', since he insinuated that a friend gave him a report of a lecture he heard in Paris.[35] Anyway, the text gives an outline of Bacon's empiricist natural philosophy at this early stage, which demands that the investigation of natural facts must make use of the senses and has to start from a materialist position as it had been conceived by Empedocles and Democritus. It should be mentioned that the contents of the *Redargutio* reminds the reader of Bacon's much longer text *Cogitata et Visa* or *Thoughts and Conclusions* from 1607.

The *Redargutio* deplores that natural philosophy lacks an agreement about first principles and states that the existing methods of demonstration are not convincing. Evidence based on sensation and experience should provide the basis for positions of knowledge. Further on a preliminary preparation of the human mind is demanded, before the work of investigation is taken up (recognition of the four idols). The speech of the Unknown Stranger emphasizes man's competence of knowledge acquisition as the key for analysing nature. Thus there can be no limitation of thinking and discovery to the well-known theories of antiquity, since the goal of science must be a fresh approach towards things – and that means to knowledge.

As a prototype of philosopher Aristotle is discredited, because of the 'question of engineering a new path.'[36] The speaker protests against prejudices, false opinions, and established speculative systems. 'The difficulty is that the usual rules of argument do not apply, since we are not agreed on first principles.'[37] Therefore the arbitrariness of procedure in traditional natural investigation necessitates the cleaning of the main instrument: the understanding has to be brought to the insight of its own distortions.

The ensuing criticism of Greek dialectics and logics as disciplines takes no wonder, because they do not produce useful knowledge, which can be used time and again. Thus the Greeks obviously lacked an enormous amount of empirical knowledge, so that the moderns have to be preferred in any querelle. All Greek methods are questioned,

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[34] Farrington B., *The Philosophy of F. Bacon* 45.
[35] Ibid., 104.
[36] Ibid., 107.
[37] Ibid., 108.

whether they were put forward by (1) the Sophists or (2) the Schools (Plato, Aristotle, Zeno, Epicurus, Pythagoras). Only the natural philosophers make an exemption (3): Empedocles, Heraclitus, Democritus, Anaxagoras, and Parmenides.[38]

The Unknown Stranger criticizes Aristotle, who cannot sufficiently explain the structure of the world, because he takes his explanations from his abstract categories, defines basic features of nature through the pair of concepts 'act' and 'potency'. He also stamps himself uncritically as the greatest authority throughout.

Beyond any dictating to human understandings it is suggested that natural philosophy aims at knowledge of forms or general laws, but this knowledge cannot be gained simply by referring to abstract form as such. What is needed is induction. In this text not only the ancients are criticized. The same is true for Telesio, Gilbert, Fracastaro, and Cardanus, who construed individual theories without reaching a generall explanatory framework for all of them. 'Truth must be discovered by the light of nature, not recovered from the darkness of the past.'[39] The work of the artisans showed the way, but it had to be perfected by method to be constituted through scientia operativa.

In science, perfect knowledge of the inner workings of nature was the ultimate goal, but this knowledge could best be attained through the investigation of the arts which related to everyday life. The value of knowledge in this area would be proved by its capacity to yield socially beneficial rewards. Hence, by establishing the mechanical arts as the most satisfactory territory for scientific enquiry, it was possible for Bacon to claim that truth and utility were the very same things. He was not lapsing into naïve utilitarianism in claiming that the basic rule for natural philosophers was 'that all knowledge is to be limited by religion, and to be referred to use and action', or alternatively 'Now the true and lawful goal of the sciences is none other than this: that human life be endowed with new discoveries and powers.' By the judicious application of the inductive method of 'literate experience' it was anticipated that innovation would become systematic and productive; the new rational foundation would overcome the reliance of the arts on sporadic and random improvements.[40]

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[38] See: Barnes J., *Early Greek Philosophy* (Harmondsworth: 1987).
[39] Farrington B., *The Philosophy of F. Bacon* 121.
[40] Webster Ch., *The Great Instauration* 337.

If one takes that demand into consideration, the results reached by the alchemists, are only gained by chance in trial and error experiments. They are not founded on method. The same is true for natural magic or for astrology.[41] But future science presupposes patient observation for discovering the secrets of nature, grounded on her subtlety and the obscurity of things.[42] Bacon's constitution of natural forms chooses the method of 'production'.[43] This mode of research finally does connect the empirical approach with (1) understanding the procedures of nature, and (2) with transferring the knowledge of nature's procedures on matter in technological production, for example in the construction of machines.

3. *Georg Agricola (1494–1555)*

Whereas Bernard Palissy as a Calvinist had severe difficulties in his life, which led to several accusations because of heresy, so that the Duke de Montmorency had to save him from Catherine of Medici, he ended his life in the Bastille.[44] Georg Agricola in contrast to that had an unproblematic career in Protestant Saxonia, though he upheld bis Catholic faith throughout his life. Agricola was a teacher, a physician, and the inaugurator of mining engineering. He attended the Grammar School at Glogau and studied at the University of Leipzig, where he graduated in 1515 as a *baccalaureus artium* and subsequently taught at the arts faculty until 1517. In Zwickau he worked as a substitute headmaster of the Grammar School and went 1522 to Bologna to study medicine and languages, obviously with success, since Aldus Manutius in Venice employed him for the edition and revision of his Galen and Hipparchus editions. In 1526 Agricola returned to Germany and settled as a pharmacist in St. Joachimsthal, where he came in close contact with the miners. He began to study mining, the geology of the region, and mining law. In 1528 he finished a first version of his great work *De Re Metallica*, which was printed by Plateanus and prefaced by

[41] See: Vickers B., "Kritische Reaktionen auf die okkulten Wissenschaften in der Renaissance", in Bergier J.F. (ed.), *Zwischen Wahn, Glaube und Wisenschaft. Magie, Astrologie, Alchemie und Wissenschaftsgeschichte* (Zürich: 1988).

[42] Cf. Farrington B., *The Philosophy of F. Bacon* 127.

[43] Ibid., 128.

[44] Cf. Jaumann H., "Palissy, Bernard", in Jaumann H. (ed.), *Handbuch Gelehrtenkultur der Frühen Neuzeit.* Band 1: *Bio-bibliographisches Repertorium* (Berlin-New York: 2004) 489.

Erasmus of Rotterdam. In 1530 Agricola took up the position of town physician in Chemnitz. He wrote an important work on measurement and weights, which – as all his later work – was published by Froben in Basel. Agricola expanded and revised his *De Re Metallica* into a substantial and for a long time unique text-book. It was published in 1556, one year after his death. Because of his Catholic faith the Duke forbade his burial in Chemnitz, but he was given a grave in the church of the neighbouring Zeitz.[45]

In his *Introduction to the Literature of Europe in the Fifteenth, Sixteenth, and Seventeenth Centuries* Henry Hallam mentions Agricola as a man of 'perfect knowledge of the processes of metallurgy'.[46] In his entry on Agricola Hallam quotes Cuvier, who wrote about the author of *De Re Metallica*:

> He is the first mineralogist who appeared after the revival of science in Europe. He was to mineralogy what Gesner was to zoology; the chemical part of metallurgy, and especially what relates to assaying, is treated with great care, and has been little improved down to the end of the eighteenth century.[47]

Cuvier's statement takes no wonder, when it is related to Agricola's treatment of his subject matter in *De Re Metallica*. His style is clear-cut and proves that Agricola is exclusively interested in establishing sound and rational methods for the whole complexity of endeavours related to mining. He argues with vehemence against all impostors and pseudo-scientists repudiating alchemy, magic, sheds irony on superstition and loathes incompetence.[48] This was a man for Bacon's taste, who mentioned Agricola favourably in *De Augmentis Scientiarum*:

> But the mechanic of which I now treat is that which has been handled by Aristotle promiscuously, by Hero in spirituals, by Georgius Agricola, a modern writer, very diligently in minerals, and by many other writers in particular subjects;[49]

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[45] Cf. Ilgauds H.-J., "Agricola, Georgius", in Wussig H.L. (ed.), *Fachlexikon abc Forscher und Erfinder* (Thun-Frankfurt am Main: 1992) 13–15; Jaumann, "Agricola, Georg", in H. Jaumann, *Handbuch Gelehrtenkultur* I, 11–12.

[46] Cf. Hallam H., *Introduction to the Literature of Europe in the Fifteenth, Sixteenth, and Seventeenth Centuries* (London: n.d.) 227.

[47] Hallam, *Introduction*.

[48] See: Georg Agricola, *De Re Metallica Libri XII. Zwölf Bücher vom Berg- und Hüttenwesen*, ed. C. Schiffner (Wiesbaden: 2003) XVII–XXIII (Dedication to the Dukes Moritz and August of Saxonia) and passim.

[49] Bacon, *Works* I, 572 and *Works* IV, 366.

The importance of Agricola's *De Re Metallica* for Bacon has theoretical reasons and an objective background. Agricola provided a thoroughly written text-book, which explained methodically how to get hold of the treasures of nature hidden deep in earth and rock. The clear presentation of the different branches of knowledge related to mining became exemplary in Europe. The Latin version of the book came quickly to England, but the Italian Michael Angelo Florio, who lived in London, translated *De Re Metallica* into Italian and dedicated the work in 1563 to Queen Elizabeth, who had a good command of that language. Agricola's text-book taught methods of mining, which were indispensable and thus his procedures were imitated all over the world, last not least in the Spanish mines of South America (Bolivia).

A servant of Francis Bacon, Thomas Bushell, was well read in Agricola and he obviously followed a hint given by his master. Bushell, who became a mining engineer, had entered Bacon's household in 1608, when he was fifteen years of age. He worked for Bacon until the latter's death in 1626. Bushell was a successful manager of mines in the Mendip Hills as well as in Cardiganshire. His success is unthinkable without the competence acquired from his study of Agricola.

> All his life he acknowledged his debt to Bacon for the theory on which his very successful practice rested. A contemporary puff, in connection with his concession to work the Somerset mines, claims that the whole enterprise rested on 'the Lord Chancellor Bacon's philosophical theory in mining discoveries, which (it is confessed) did light the first candle to these and all other mines of the like nature.'[50]

This obviously means that Bacon had introduced Busshel to Agricola's works. In his writings time and again the metaphor of mining is used in order to emphasize the deep researches of the natural philosopher. But there are occasionally passages in Bacon, where he with interest and curiosity speaks about mining, for example in *Historia Densi et Rari*.[51]

A Postscript on the Secrets of Nature

Palissy's experiments as an alchemist and a potter on the base of his empiricist outlook (represented in Shells brilliant article) makes it

[50] Farrington, *The Philosophy of F. Bacon* 34. Farrington gives as the source for his Bacon quotation: *Bacon's Collected Works*, ed. Blackbourne (London: 1730) vol. I, 150.

[51] Cf. Bacon, *Works* V, 344–45.

implicitly more than plausible to assume that Francis Bacon on the one hand was fascinated by Palissy's endeavours and on the other hand by a kind of affinity to a Paracelsian outlook. In Palissy's unending trials and experiments to imitate the workings of nature, for which the principle of heat (generation; pottery) played an important role, we might see beginnings of Bacon's theories of matter – and of his later theories of life, which have been disclosed by Graham Rees in long years of research.[52]

The problem of secrets in nature,[53] prominent in Renaissance variants of science, had been still relevant in the transitional period from the 16th to the 17th century, which led up to early modern new philosophy. The ambiguity of the concept of 'the occult'[54] therefore must be taken into account, first as an indicator of limits for human knowledge (in Augustine's sense) and as a challenge for the human intellect to overstep the boundaries constituted by the medieval doctrinal authorities (the Roman Church and the official teachers of scholastic philosophy). If 'the occult' is seen as hidden in nature from direct human access or insight, it remains yet explicable and thus may be related to Francis Bacon's 'Weltversteckspiel'.[55] Concerning 'the occult' we may set against each other a traditional thesis and its early modern anti-thesis:

> Thesis
> In nature occult and invisible workings take place, which are inexplicable for the human mind. Invisibility makes them not intelligible and so the causes of occult processes remain unknown. (At this point the pseudo-sciences come in in order to provide explanations with reference to supernatural powers. Magical effects had ben explained by the assumption that bodies have occult powers as Giambattista Della Porta stated.)[56]

[52] Cf. Rees G., "Bacon's speculative philosophy", in Peltonen M. (ed.), *The Cambridge Companion to Bacon* 121–145.

[53] Cf. the excellent paper by Hutchison, "What happened to Occult Qualities?".

[54] See: Vickers B., "Kritische Reaktionen" as well as: Shumaker W., *The Occult Sciences in the Renaissance. A Study in Intellectual Patterns* (Berkeley-Los Angeles-London: 1972).

[55] Cf. Blumenberg H., *Der Prozeß der theoretischen Neugierde* (Frankfurt am Main: 1973) 196–99; Bacon, *Works* vol. III, 299 (*The Advancement of Learning*).

[56] Cf. Henry J., *Knowledge is Power. How Magic, the Government and an Apocalyptic Vision inspired Francis Bacon to create Modern Science* (Duxford-Cambridge: 2002) 43 and passim.

> Anti-Thesis
> Invisibility does not exclude intelligibility. If the method of investigation cannot be directed at causes, it should be focussed on effects. The experimental method leads to results, which make the systematic repetition of an effect (found out by experiment) possible. Bacon would speak of 'scientia operativa', which however does not cover all disciplines, since there is also scientia non-operativa like astronomy. 'The occult' is given no essentialist status by Bacon, but a functionalist. Occult causes can be grasped ex negativo through effects. When the effects are under control, then the 'form' is disclosed.[57]

Bacon's development of his idea of nature and 'the occult' covers a long period, which reaches from 1603 to the 'quinquennium', the noble last five years.[58] In 1603–1609 we find in Bacon's mostly unpublished manuscripts the first sketches of his new experimental and/or inductive method, which is related to his criticism of alchemy, astrology, and magic.[59] About 1605 – the year, when *The Advancement of Learning* appeared in print – Bacon became interested in atomism and held close contacts to the Northumberland circle. One has to remember within this context that Bacon was an atomist and an anti-atomist at different stages of his career.[60] From 1612 onwards Bacon's conception of atomism changed and even was transformed into a specific corpuscular theory. This development found expression Fe in *De principiis atque originibus* (ca. 1612–20).

> The doctrine of Democritus concerning atoms is either true or useful for demonstration. For it is not easy either to grasp in thought or to express in words the *genuine subtlety of nature*, such as it is found in things, without supposing an atom.[61]

According to Bacon the theory of atoms proves or explains a rational world order more convincingly than the somewhat simplistic Aristotelian

[57] Cf. Zittel C., "'Truth is the daughter of time'. Zum Verhältnis von Theorie der Wissenschaftskultur, Wissensideal, Methode und Wissensordnung bei Bacon", in Detel W. – Zittel C. (eds.), *Wissensideale und Wissenskultur in der Frühen Neuzeit* (Berlin: 2003) 213–238.

[58] Cf. Bowen C.D., *Francis Bacon. The Temper of a Man* (New York: 1993) 207–233.

[59] Long before Bacon there were heavy attacks on astrology by Pico della Mirandola. Cf. Vickers B., "Kritische Reaktionen" 202–211.

[60] Cf. Kargon R.H., *Atomism in England from Hariot to Newton* (Oxford: 1966) 43.

[61] Bacon, *Works* 287. Emphasis J.K. Cf. Zittel C., "Truth is the daughter of time" 217.

doctrine of the four elements: 'an Army of infinite small portions or seeds implaced'[62] makes a creator of order necessary.

At this point it should be mentioned that Paracelsus believed, when he developed his three principles, that he had overcome the conceptual and philosophical limits of Aristotle's doctrine of the four elements.[63] Instead of Aristotle's complicated, but only bookish and combinatory apparatus of natural philosophy, Paracelsus introduced the three principles ('tria prima') salt, sulphur, and mercury.[64]

> Man Verstand [unter Salz] alles Starre und Feuerbeständige im Gegensatz zum Schwefel, der als das Prinzip des Brennbaren, und zum Quecksilber, das als das der Flüchtigkeit und des metallischen Charakters betrachtet wurde.[65]

For Paracelsus the creation is seen as the ,chemical unfolding of nature',[66] so that he develops the concept of a chemical universe. The earth then is a 'vast chemical laboratory',[67] which Paracelsus tends to understand by means of the theoretical patterns of analogy, sympathy, and antipathy, studying the correspondences between the macrocosm and the microcosm. Paracelsus already combined a 'strong reliance on observation and experiment'[68] with distrust in mathematical abstraction and a high regard for a Christian neo-Platonic and Hermetic philosophy, the latter of which remained partially within a framework of the old conception of 'the occult', as it was represented by Marsilio Ficino and Agrippa of Nettesheim.[69] It takes no wonder than that Paracelsus

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[62] Bacon, *Works* XII, 338.

[63] Cf. Debus A.G., *Man and Nature in the Renaissance* (Cambridge: 1978) 16–33; Westfall R.S., *The Construction of Modern Science, Mechanism, and Mechanics* (Cambridge: 1977) 66–69.

[64] Arabic scholars in the eighth century AD had already established a new theory of metals, according to which mercury and sulphur brought into perfect proportion, would produce gold. Cf. Debus A.G., *Man and Nature* (n. 61) 17. On Geber's (Abu Moussa Dschafar al Sofi) theory concerning the relation of mercury and sulphur in gold and on the function of the Philosopher's Stone cf. Bauer H., *Geschichte der Chemie I* (Berlin-Leipzig: 1914) 28–30. Cf. further: Rossi P., *La Nascita Della Scienza Moderna* cap. 10.

[65] Bauer H., *Geschichte der Chemie* I, 29.

[66] Debus A.G., *Man and Nature* 23.

[67] Ibid., 25.

[68] Ibid., 21.

[69] See: Agrippa v. Nettesheim, *De Occulta Philosophia. Drei Bücher über die Magie* (Nördlingen: 1987); Müller-Jahncke W.-D., *Magie als Wissenschaft im frühen 16. Jahrhundert. Die Beziehungen zwischen Magie, Medizin und Pharmazie im Werk des Agrippa von Nettesheim (1486–1535)* (Marburg: 1973).

acknowledged two Books of Truth, first Nature and then the Bible and it is no surprise that as an Anti-Aristotelian he rejected the doctrine of humours in medicine.

In the second part of his *Novum Organum* Bacon suggests a revision even of his intermediate post-1612 version of atomism, because he then gave up his convictions concerning the unchangeability of matter and his conception of the void. In his late years Bacon developed two parallel systems within his natural philosophy:

system of induction	speculative philosophy (Semi-Paracelsian Cosmology).[70]

In the last analysis Bacon was no mechanist philosopher. His theory of matter underwent an important transformation and that means: he moved into the direction of forming conceptions, which we nowadays would subsume under the discipline of biology rather than under physics. Bacon distinguishes between non-spiritual matter and spiritual matter. The latter, also called 'subtle matter' or 'spirit' reminds more of Leibniz's 'monads' than of mechanically defined and materially as well as spatially determined atoms. The spirits are seen as active agents of phenomena; they are endowed with 'appetition' and 'perception'.[71]

These spirits are never at rest. In the *Novum Organum* then Bacon rejected the 'existence of eternal and immutable atoms and the reality of the void'.[72] His new conception of matter is 'close to that of the chemists' and here we already can refer to Bacon's Semi-Paracelsian Cosmology.[73] The careful natural philosopher tries to disclose the secrets of nature step by step and therefore Bacon comments on his method:

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[70] See: Rees G., "Francis Bacon's Semi-Paracelsian Cosmology", *Ambix*, XXII (1975) 81–101; Rees G., "Francis Bacon's Semi-Paracelsian Cosmology and the Great Instauration", *Ambix*, XXII (1975) 161–73; Rees G. – Upton Chr., *Francis Bacon's Natural Philosophy: A New Source* (British Society of the History of Science: 1984).

[71] Cf. Bacon's definition of 'spirit' in Bacon, *Works* vol. I, 320–321 (*Historia Vitae et Mortis*); as well as in *Works* V, 63 (*Sylva Sylvarum*, Century IX): 'It is certain that all bodies whatsoever, though they have no sense, yet they have perception: for when one body is applied to another, there is a kind of election to embrace that which is agreeable, and to exclude or expel that which is ingrate'.

Cf. further: Kargon R.H., *Atomism in England* 49.

[72] Cf. Kargon, *Atomism in England* 47.

[73] Cf. Rees G., "Francis Bacon", in Applebaum W. (ed.), *Encyclopedia of the Scientific Revolution from Copernicus to Newton* (New York-London: 2000) 65–69.

'I propose to establish progressive stages of certainty.'[74] This aims at his inductive procedure and that means his method of the tables, which is a complicated mode of induction by exclusion. It is necessary, because nature hides her secrets. In aphorism XIX of Book One in his *Novum Organum* Bacon writes:

> There are and can be only two ways of searching into and discovering truth. The one flies from the senses and particulars to the most general axioms, and from these principles, the truth of which it takes for settled and immoveable, proceeds to judgment and to the discovery of middle axioms. And this way is now in fashion. The other derives axioms from the senses and particulars, rising by a gradual and unbroken ascent, so that it arrives at the most general axioms last of all. This is the true way, but as yet untried.[75]

The laws of nature, which Bacon intends to find out by means of his new method are expressed in the 'forms', in which as results the 'unbroken ascent' culminates. Through these forms the natural philosopher understands the general causes of phenomena.[76] In his endeavour to learn more about the secret workings of nature, Bacon came to the conviction that the atomist theory could not provide sufficient explanations for the 'real particles, such as really exist',[77] because he thought that unchangeability of matter and the void (both necessary assumptions for atomism) had become untenable. Bacon's language turned from that of Greek physics to the usage of contemporary chemists. This is due to his insight that 'subtlety of investigation' is needed, since our senses are too gross for the complexity and fineness of nature, so that method has to compensate for the shortcomings of our direct grasp. Only method leads to the knowledge of nature.[78]

Bacon distinguishes 'animate' or vital spirits, which are continuous and have a similar substance as fire from lifeless ort inanimate spirits, which are cut off and resemble air. The spirits interact with gross matter

[74] Bacon, *Works* IV, 40 (*Novum Organum*, Preface).
[75] Bacon, *Works* IV, 50.
[76] Cf. Kargon, *Atomism in England* 48.
[77] Bacon, *Works* IV, 126 (*Novum Organum*, II, viii).
[78] In *Sylva Sylvarum*, Century I, 98 (posth. 1627) Bacon explicitly deals with the question of the asymmetrical relationship between man's natural instrument (= the senses) and the intricacy of nature's structures and workings. He discusses spirits of bodies as well as their tangible parts and emphasizes that the invisible processes of nature are principally and exactly those which govern her. Cf. Bacon, *Works* II, 380–82.

through chemical processes.[79] These spirits have two different desires: self-multiplication and attraction for like spirits. 'Bacon's later theory of matter is one of the interaction of gross, visible parts of matter and invisible material spirits, both of which are physically mixed.'[80] For Bacon spirits interact with matter by chemical processes like concoction, colliquation and other non-mechanical processes, so that he cherishes a scientific paradigm, which does not converge with Descartes' mechanist theory of matter, which presupposes 'res extensa' moving in space. Bacon's theory of matter is according to Graham Rees closely related to his speculative philosophy: 'The distinction between tangible and pneumatic matter is the hinge on which the entire speculative system turns.'[81] Already Paracelsus had stated that knowledge inheres in the object.[82]

Bacon's theory of matter in its last version was more a corpuscular theory than a theory of atoms.[83] Bacon's particles are semina rerum: they are endowed with powers, which make a variety of motions possible and allow the production of all possible forms. As Antonio Clericuzio has shown these spirits are constitutive for Bacon's theory of matter. As material, fine substances, composed of particles, combined from air and fire, they can – as has been emphasized above – be inanimate or inanimate. Bacon in a way suggests a corpuscular and chemical chain of being, since:

inanimate objects	→	inaugurate spirits
vegetables	→	inanimate + vital spirits
animals	→	vital spirits.

It takes no wonder then that Bacon's spirits are indispensable for his conception of physiology or – as Graham Rees stated –:

> the vital spirits regulate all vegetative functions of plants and animals. Organs responsible for these functions, for digestion, assimilation, etc., seem to act by perception, mere reaction to local stimuli, but these reactions are coordinated by the vital spirit. These functions flow from the

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[79] Cf. Bacon, *Works* IV, 195–196 (*Novum Organum*, II, xl).
[80] Kargon R.H., *Atomism in England* 51.
[81] Rees G., "Bacon's speculative philosophy" 125.
[82] Cf. Shell H.R., "Casting Life" 32.
[83] Cf. Clericuzio A., *Elements, Principles and Corpuscles. A Study of Atomism and Chemistry in the Seventeenth Century* (Dordrecht-Boston-London: 2000) 78.

> spirit's airy-flamy constitution. The spirit has the softness of air to receive impressions and the vigour of fire to propagate its actions.[84]

This physiological stratum of Bacon's natural philosophy, however, cannot be separated from his Semi-Paracelsian[85] Cosmology, which has been reconstructed by Graham Rees from the existent parts of the *Instauratio Magna*.[86] A short reference to Bacon's theory of the 'quaternions' has necessarily to be given here.

Bacon's speculative system is a hybrid constituted from different sources providing seminal ideas for example atomism, Aristotelianism, Arabian astronomy, Copernican theory, Galileo's discoveries, the works of Paracelsus, and Gilbert. What he does in his theory is to combine astronomy (referring to Alpetragius)[87] and chemistry:[88] '[it] was partly designed to fit a kinematic skeleton and explain, in general terms, the irregularities of planetary motion as consequences of the chemical constitution of the universe.'[89] Bacon sees the universe as a finite and geocentric plenum, in which the earth consists of the two forms of matter mentioned above (tangible, pneumatic). The earth owns a tangible inside and is in touch with the surrounding universe, but through an intermediate zone. Between the earth's crust and the pure pneumatic heavens this zone exists; it reaches some miles into the crust and some miles into air. In this zone then pneumatic matter mixes with tangible, thus producing 'attached spirits', which have to be distinguished from 'free spirits' outside tangible bodies. Bacon's four kinds of free spirits are relevant for his 'quaternion theory':

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[84] Rees G., in *Bacon F., Philosophical Studies c. 1611–1619. The Oxford Francis Bacon* VI (Oxford: 1996) 202–3.

[85] On Paracelsus see: Boas M., *The Scientific Renaissance 1450–1630* (London-Glasgow: 1970) 148–154; Müller-Jahncke W.-D., *Astrologisch-Magische Theorie und Praxis in der Heilkunde der Frühen Neuzeit* (Stuttgart: 1985) 67–88; Schmitz R., *Geschichte der Pharmazie II. Von der Frühen Neuzeit bis zur Gegenwart*, Friedrich Chr. – Müller-Jahncke W.-D. (eds.) (Eschborn: 2005) 267–343.

[86] Rees G. – Upton Chr., *Francis Bacon's Natural Philosophy* 20–21. As Bacon did not live long enough to finish Part Five of Instauratio Magna, the reconstruction of his speculative philosophy proved to be demanding and difficult.

[87] On Alpetragius (Al-Bitrūjī) cf. Rees – Upton, *Francis Bacon's Natural Philosophy* 26 and: Gaukroger S., *Francis Bacon and the Transformation of Early-Modern Philosophy* (Cambridge: 2001), 172–75 and Grant E., *Planets, Stars, & Orbs. The Medieval Cosmos 1200–1687* (Cambridge: 1996) 563–566.

[88] Bacon was presumably influenced by Joseph Duchesne. Cf. Rees, "Francis Bacon's Semi-Paracelsian Cosmology" 84–85.

[89] Rees, "Francis Bacon's Semi-Paracelsian Cosmology" 94. Bacon, however, could not explain the planetary retrogressions astronomically.

– air		– ether	
	sublunary		celestial
– terrestrial fire		– sidereal fire	

The planets move around the earth in ether (tenuous kind of air), which belongs to the 'mercury quaternion', which includes watery bodies and mercury. Terrestrial fire is a weakened form of sidereal. It is related to oily substances and sulphur constituting the 'sulphur quaternion'. The two quaternions oppose each other: air/ether vs. fire/sidereal fire. Air and ether lose power, when terrestrial and sidereal fires grow more energetic. – It is important to note that Bacon's sulphur and mercury are no principles in the sense of Paracelsus, but simply natural substances. The principle of salt is excluded by Bacon and the substance plays only a role for the sublunary realm.[90]

Bacon used his quaternion theory for his cosmology, which differs much from contemporary systems:[91]

– the diurnal motion turns the heavens about the earth towards the west;
– under powerful sidereal fire (= principle of celestial motion) the motion is swift: the revolution of the stars takes place in twenty-four hours;
– under weaker sidereal fire – nearer to the earth – planets move more slowly and more erratic.

Bacon, who tries to conceive a unified physics, rejected different modes of motion in the superlunary and in the sublunary world.[92] He neither believed in the existence of the (crystalline) spheres nor in the macrocosm-microcosm analogy. Bacon revised Paracelsian ideas thoroughly. He rejected the grounding of his theories in Scripture and he ignored Cabbalistic and Hermetic tendencies completely.[93] But he extended the explanatory powers of the quaternions to earthly phenomena like wind and tide.

[90] Cf. Rees G. – Upton Chr., *Francis Bacon's Natural Philosophy* 25.
[91] Cf. Rees G., "Francis Bacon" 68.
[92] Cf. Bacon, *Works* I, 329.
[93] Cf. Rees G., "Francis Bacon's Semi-Paracelsian Cosmology" 90–91.

Bacon's two systems were closely connected:

System 1: (The Two Quaternions) explained and comprised the cosmological aspect of his natural philosophy.
System 2: (Theory of Matter) explained terrestrial nature, resp. 'dealt with the manifold changes in the animal, vegetable, and mineral kingdoms of the frontier zone between the celestial heavens and the Earth's interior.'[94] (2) depends on (1), since explanations for terrestrial things were subordinated to explanations of the cosmological level. The table of system 2 shows Bacon's matter theory.

The quaternion theory is relevant for system 1, system 2 is explained in terms of 'intermediates'. These intermediates combine the qualities of the items in one quaternion with their opposites in the other.

Bacon's system is built in a clear symmetrical way: each quaternion has four segments, together eight and there are four types of intermediates. Thus the system altogether distinguishes twelve segments. By this apparatus Bacon wanted to explain all natural phenomena:

The Two Quaternions

	SULPHUR Q.	MERCURY Q.
TANGIBLE SUBSTANCES (WITH ATTACHED SPIRITS)	Sulphur (subterranean)	Mercury (subterranean)
	Oil and oily inflammable substances (terrestrial)	Water and 'crude' non inflammable substances (terrestrial)
PNEUMATIC SUBSTANCES	Terrestrial fire (sublunary)	Air (sublunary)
	Sidereal fire (planets)	Ether (medium of the planets)

[94] Cf. Rees G., "Francis Bacon's speculative philosophy" 130. The two tables are taken from Graham Rees, who has developed them already in 1975 in his essay "Francis Bacon's Semi-Paracelsian Cosmology".

The Theory of Matter

	SULPHUR Q.	INTERMEDIATES	MERCURY Q.
TANGIBLE SUBSTANCES (WITH ATTACHED SPIRITS)	Sulphur (subterranean)	Salts (subterranean and inorganic beings)	Mercury (subterranean)
	Oil and oily inflammable substances (terrestrial)	Juices of animals and plants	Water and "crude" non inflammable substances (terrestrial)
PNEUMATIC SUBSTANCES	Terrestrial fire (sublunary)	Attached animate and inanimate spirits (in tangible bodies)	Air (sublunary)
	Sidereal fire (planets)	Heaven of the fixed stars	Ether (medium of the planets)

The principal intermediates are two:

The fire-air intermediates	
↓	↓
'attached' animate spirits	inanimate spirits
↓	↓
only in living bodies	in all tangible bodies (including living bodies)

Bacon's two quaternions and the matter-theory provide a speculative framework for his thought, which remains open for future knowledge acquisition and technical application. We could suggest that Bacon's *Nova Atlantis* could function as a text, which renders an intermediate position between his theory of induction and his speculative philosophy.[95]

It is important to note that Bacon's speculative system was his way out of his dilemma, which made it impossible for him to finish his Instauratio Magna. His turn towards speculation can only be interpreted as an intellectual anticipation within an intermediate phase of the history of science, when the gigantic amount of research work had not yet been completed, so that empirical theories could neither be established

[95] Cf. Klein J., 'Nachwort', in Francis Bacon, *Neu-Atlantis*, ed. J. Klein (Stuttgart: 2003) 64–79. See further: Price B. (ed.), *Francis Bacon's New Atlantis. New interdisciplinary essays* (Manchester: 2002).

nor sufficiently warranted. Speculation in Bacon's sense can therefore be seen as a means of explaining the secrets of nature by substitution until the speculations themselves have been caught up with methodical research. The speculative stance remains a relative and intermediate procedure for the 'man of science'

4. *The Doctrine of Twofold Truth*

In order to construe solid foundations for effective science and technology, the limitations of the mind had to be overcome. Bacon's theory of the idols plays a role here together with his criticism of classical and modern natural philosophy, which has been mentioned so far. The reformation of the conception of knowledge was supported by the doctrine of the two modes of truth: truth of God or divine truth and truth of nature (God's creation). Bacon conceded that we cannot know divine truth, since God's will remains outside our ken and outside Holy Scripture. But we are able to understand the truth of his works, that is nature. According to Calvin God gave the gift of understanding to man that he may grasp the workings of nature in order to admire the creator's ingenuity. This was a clever plea by Bacon for man's freedom of thought,[96] which could not be based on authority and belief. Through the doctrine of the twofold truth philosophical and theological truths could exist side by side, though they had contradictory contents. Bacon was convinced that there is 'no [...] enmity between God's word and his works.'[97]

The new science introduces a new understanding of God's will, which up to that point had exclusively been the subject of investigation for the Christian theologian. Now God's will can be studied 'by means of a new method', namely the method of natural science, so that the structures or laws of nature, which are discovered by the scientists, allow indirectly –

[96] Cf. Lange F.A., *Geschichte des Materialismus* 181. 'In Wirklichkeit musste, bevor es zum directen Verkehr mit den Dingen kommen konnte, die Autorität des Aristoteles erst gebrochen werden.' Ibid., 188.

[97] Bacon, *Works* III, 486.

by inferences from the creation to its Creator – an insight into God's will, which had not been mentioned in Holy Scripture.[98]

5. *Induction, Workshops, and* scientia operativa

Bacon begins his Novum Organum with a criticism of pure logic as method in science and gives his support instead to an enhancement of human powers through application of knowledge to reality. But before knowledge can be applied to reality, it must be acquired. For Bacon it must be acquired by finding out the workings of nature or her procedures of production and transformation as the 'how'. Here it is important to see in which way Bacon explains the structure of matter.[99] At the same time taxonomy in Bacon is given another function, because it seems to loose the power of explanation. Bacon defines topics as 'mixtures of logic with the matter of sciences' or as a combination of ars inveniendi and inventio. The places function as directions of invention and inquiry.[100] So when Bacon uses taxonomy, it is closely connected to his theory of induction and his experimental science: he wrote lists of open questions, thus collecting problems, which science or natural philosophy has to solve in the future. It takes no wonder then that Bacon saw science as a collective and cooperative endeavour. In his *Baconiana* of 1679 Archbishop Tenison had written that Bacon 'wanted to find out 'the several actions and passions of bodies' and how 'they may be made serviceable to human life'. 'Now this was a work for a man of a thousand hands and as many eyes, and depended upon a distinct and comprehensive history of Nature.'[101]

Bacon inaugurated a close relationship between science and technology, because he wanted to produce works on the grounds of new knowledge about the procedures of nature.[102] Thus he had in mind

[98] Klein J., "Francis Bacon (1561–1626): Natural Philosophy as Theodicy", in Freiburg R. – Gruss S. (eds.), *But Vindicate the Ways of God to Man: Literature and Theodicy* (Tübingen: 2004) 53–54.

[99] Cf. the section on the secrets of nature. Bacon commented on this subject already in *De principiis atque originibus.*

[100] Cf. Francis Bacon, *The Advancement of Learning*, ed. G.W. Kitchin (New York, London: 1962) 129.

[101] Bishop Tenison, *Baconiana* (1694), quoted after: Farrington B., *The Philosophy of Francis Bacon* 32.

[102] Cf. Mumford L., *Mythos der Maschine. Kultur, Technik und Macht*, transl. by L. Nürenberger and A. Hälbig (Frankfurt am Main: 1977) 456.

the extension of his scientific method to every branch of human life. Bacon's ideas concerning organisation in favour of systematic scientific research and application of results within the field of technology orientates science for the benefit of mankind. Here the conception of *Paradise Regained* plays an important role, which could also be interpreted as a version of theodicy. Under the idea of Paradise Regained – to use an anachronistic metaphor and book title[103] – only positive effects are connected with science. The danger of negative consequences on the grounds of scientific-technological development in the sense of innovation and aftermath[104] is foreign to Bacon.

Science providing technology then can be named scientia operativa. For Bacon these conceptions had a utopian touch as one can see in his *Nova Atlantis*. He aligned human thought towards the construction of machines as tools by the help of which man can compensate the negative consequences of the Fall: 'In the presence of thy sweat thou shalt eat your bread.' The construction of Bacon's new science had become possible within the framework of his doctrine of double truth, which opened the chance to establish inductive science as scientia operativa. Earlier technological progress had been made due to empirical and experimental ad hoc methods, related to the tradition of the workshops. Bacon helped to close the gap between science and technology:

Science:	technology:
True, but useless	useful, but low and servile.

So new science, as has been indicated, had to be based on collective enterprises, which alone guarantee relevance:

> But certain it is, that vnto the deepe, fruitefull, and operatiue studie of many sciences, specially Naturall Phylosophy and Physicke, Bookes be not onely the Instrumentals; wherein also the beneficence of men hath not beene altogether wanting: for we see, Spheares, Globes, Astrolabes, Mappes, and the like, haue bene prouided, as appurtenances to Astronomy & Cosmography, as well as bookes: We see likewise, that some places instituted for Physicke, haue annexed the commoditie of Gardeins for Simples of all sorts, and do likewise command the vse of dead Bodies for Anatomyes. But these doe respect but a few things. In generall, there

[103] John Milton's *Paradise Regained* was published in 1671.

[104] See: Specht R., *Innovation und Folgelast. Beispiele aus der neueren Philosophie- und Wissenschaftsgeschichte* (Stuttgart-Bad Canstatt: 1972).

> will hardly be any Mayne proficience in the disclosing of nature, except there be some allowance for expences about experiments; whether they be experiments appertaining to *Vulcanus* or *Dedalus*, Furnace or Engyne, or any other kind; And therefore as Secretaries, and Spyalls and Intelligencers of Nature, to bring on their Billes, or else you shall be ill aduertised.[105]

Bacon states that for the scientific and technological development man's hand needs help, namely instruments:

> the senses... are very sufficient to certify and report truth though not always immediately, yet by comparison, urging much things as are too subtle for the sense to some effect comprehensible by the sense, and other like assistance. But they [advice for representatives of Academic Scepticism] ought to have charged the deceit upon the weakness of the intellectual powers, and upon the manner of collecting and concluding upon the reports of the senses. This I speak, not to disable the mind of man, but to stir it up to seek help: for no man, be he never so cunning or practical, can make a straight line or perfect circle by steadiness of hand, which may be easily done by help of a ruler or compass.[106]

Bacon's task within scientia operativa and thus in the technical disciplines is it to fill the gaps of nature by his inductive method.[107] These gaps or blanks can only be filled up, if the secret workings of nature are known by methodical investigation and therewith the patterns of construction hidden in nature. These patterns must then find application in respect of the gaps nature has left for the human inquisitive mind. Here exactly we can refer back to Bacon's speculative philosophy, which gives a framework for the modes of operation in nature, which allows the explanatory interrelation between organic life processes and the structure of matter, which have to be followed into their secret processes. Thus science and technology cannot be set apart for Bacon. Scientia operativa provides possibilities for repeating extrapolations of natural workings within the products of technology, which are based on the partial identity and difference of causality and finality.[108]

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[105] Bacon, *The Advancement of Learning. The Oxford Francis Bacon* IV (2000) 58–59.
[106] Bacon, *Advancement*, ed. G.W. Kitchin 127.
[107] Cf. Moscovici, S., *Versuch über die menschliche Geschichte der Natur* (Frankfurt am Main: 1984), 108.
[108] Cf. Hartmann N., *Philosophie der Natur* (Berlin: 1950) 331–336.

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TECHNICAL KNOWLEDGE AND THE ADVANCEMENT OF LEARNING: SOME QUESTIONS ABOUT 'PERFECTIBILITY' AND 'INVENTION'

Romano Nanni

In the literature on Francis Bacon's work few attempts have been made from a philological and historical point of view to reach an understanding of exactly what his attitude was towards technics, technical knowledge and its development.[1] To introduce this theme, I would like to refer to some pages (pp. 84–91) from a classic of historiography, Paolo Rossi's *I filosofi e le macchine*. This study has made an important contribution to philosophical historiography in general, and when it first appeared it undoubtedly marked something of a turning point for Italian historiography, little inclined as it was to deal with technics. The values informing this work are not, at least as far as I am concerned, in question. However, I do have some doubts about his interpretation of the relationship between forms of knowledge (including that of the philosophers) and technics, and its implications for the concept of progress.

As Rossi quite rightly points out in his book, the whole of Bacon's work is concerned with replacing a rhetorical and literary culture with a technical and scientific one.[2] Bacon's protest against the sterility of traditional culture seems to be based on an opposition between the mechanical arts and philosophy, in other words on the opposition between *progressiveness*, a characteristic of technical and scientific knowledge, and the typically static nature of the dialectical exercises

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[1] For more about the existing literature on this topic, see Vickers B., "Francis Bacon and the Progress of Knowledge", *Journal of the History of Ideas* 53 (1992) 495–518; and, more recently, Solomon J.R. – Gimelli M.C. (eds.), *Francis Bacon and the Refiguring of Early Modern Thought. Essays to Commemorate the Advancement of Learning (1605–2005)* (Aldershot: 2005).

[2] Rossi P., *I filosofi e le macchine* (Milan: 1962) 84. Paolo Rossi is the author of many other important works about Francis Bacon: *Francesco Bacone. Dalla magia alla scienza* (Turin: 1974); 'Introduction' to Francesco Bacone, *Scritti filosofici*, ed. P. Rossi (Turin: 1986); *Il tempo dei maghi. Rinascimento e modernità* (Milan: 2006).

of the Schools and the rhetorical exercises of Humanism.[3] Knowledge in the mechanical arts is progressive and accumulative, and collaboration between researchers the norm. According to Bacon, all fields of knowledge (with the exception of poetry) should be characterized by progressiveness and collaboration.[4] For this reason Bacon distinguishes between the *inventor* and the *master*, between the person who adds his contribution to the work of his predecessor and thereby contributes to the progress of science, and the enlightened scholar. For Bacon, the inventor is the emblematic figure of the mechanical arts, while the master-pupil pairing is predominant in other fields. He thus attributes a universal value to certain typical categories of technical knowledge: collaboration, progressiveness, perfectibility, invention. These, in his view, should inform the whole field of human knowledge, though within a context of close collaboration between science and technics that also moves beyond the 'merely empirical and operational mechanics' of the mechanical arts to date.[5]

This is the essential framework of Paolo Rossi's reading of Bacon's reform of knowledge.

I would like now to look in more detail – limiting myself to Book I of *Novum Organum* (1620, Part Two, L. I, aphorisms 1–130),[6] plus some references to Book II and to *The Advancement of Learning* –,[7] at the way in which Bacon develops his argument about technics, or rather, about the mechanical arts, to use the expression definitively codified in the Middle Ages and which he continues to adopt. Of the group of concepts highlighted by Rossi, I will just examine perfectibility and, in part, invention, leaving the concepts of progressiveness, collaboration and intersubjectivity for some other occasion.

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[3] Ibid., 86.

[4] Ibid., 87.

[5] Ibid., 90–91.

[6] *Collected Works of Francis Bacon*, vol. I, part I, *Philosophical Works*, with a new Introduction by Graham Rees (London: 1996), reprint of Spedding J. – Ellis R.L. – Heath D.D. (eds.), *The Works of Francis Bacon* (London: 1879). See, for the latin text, also Francesco Bacone, *La Grande Instaurazione. Parte seconda, Nuovo organo*, parallel latin text, ed. M. Marchetto (Milan: 2002).

[7] *Collected Works of Francis Bacon*, vol. III, part I, *Philosophical Works* (London: 1996), reprint of *The Works of Francis Bacon*, Spedding J. – Ellis R.L. – Heath D.D. (eds.), (London: 1876); compare with Bacon F., *The Major Works*, ed. B. Vickers (Oxford: 2002), which is a specifically annotated edition of the original Elisabethan and Jacobean language of *The Advancement of Learning*.

The mechanical arts improve human life (NO, I, 85), writes Francis Bacon with cast-iron certainty. The ultimate goal of the sciences must therefore be to provide human life with new discoveries and new instruments (*quam ut dotetur vita humana novis inventis et copiis*, NO, I, 81). The ideal that informs Bacon's project for the reform of knowledge is therefore without doubt to orient the sciences and the whole of culture to technical and operational ends. Bacon proclaims the supreme dignity of invention in human history, the benefits of which, unlike civil benefits and those of political reform, can be enjoyed by the whole human race. They are long-lasting and offend no one. The arts make man a God for man (NO, I, 129).

Entirely consequential to the human and civil primacy of the mechanical arts is that their specific features and their mode of historical development become an exemplary normative model for the reform of knowledge. Indeed, on the one hand, writes Bacon, the sciences have been at a standstill for two thousand years, due to the fact that they are no longer permanently anchored to nature. The mechanical arts, on the other hand, insofar as they are founded on nature and the light of experience, 'are continually thriving and growing, as having in them a breath of life, at the first rude, then convenient, afterwards adorned, and at all times advancing' (NO, I, 74).

An assertion like this obviously implies an idea of continual progress obtained by means of gradual improvements. But if we examine the *Novum Organum* carefully, some cracks begin to appear in a conceptual framework that might seem to have been definitively explained and clarified in these lines.

Amongst the causes that have paralyzed *industria hominum*, that is human industry, for centuries, Bacon paradoxically lists human admiration for the great number, variety and beauty of works produced by the *mechanical arts*; in his view, this admiration has created a kind of optical distortion, the result of an excessive sense of self-satisfaction on the part of the human race, an illusion of wealth that has become a cause of poverty.

In reality, Bacon observes, behind this great variety of works there lie just a few human observations and natural processes. The rest is 'but patience, and the subtle and ruled motion of the hand and instruments – as the making of clocks (for instance) is certainly a subtle and exact work: their wheels seem to imitate the celestial orbs, and their alternating and orderly motion (*in motu successivo et ordinato*), the pulse of animals; and yet all this depends on one or two axioms of nature'

(NO, I, 85). There is a subtle, implicit devaluation of the procedures of the mechanical arts in these words.

Francis Bacon must immediately be corrected on one point: the consequential and regular movement of the clock was achieved by applying the traction exercised by a simple falling weight to a verge-and-foliot escapement, an invention that is generally dated to the end of the thirteenth century. This is how the mechanical clock came into being,[8] and it represented a break with respect to the tradition of sundials, clepsydrae, sandglasses, burning sticks and mercury clocks. This mechanism clearly functioned by virtue of certain laws of physics, and took advantage of the marked improvement in metalworking techniques that went hand in hand with the improvements that led to the invention of artillery. But behind the invention of the mechanical clock there was above all the practical trial and error and the patient perfecting of the components by the medieval *artifices*. This invention, which was the outcome of slow, manual procedures, marked a turning point in human history, bringing with it the possibility of measuring the uniform regularity of time (with everything that derives from this in terms of the perception of time). But turning points like this, which are due exclusively to human patience and manual skills, are ignored by Bacon's model.

The direction of Bacon's line of argument becomes clearer further on in the same aphorism (NO, I, 85), at the point where he once again observes that the sophistication acquired by the liberal arts, like that of the mechanical arts in the preparation of natural bodies such as wine, beer, bread, sweets and spirits, took an extremely long time and owes little to observation and the axioms of nature and a great deal to favourable circumstances and chance. But for Bacon this is not cause for appreciating the significant progress in the refinement process, but for pitying the human condition, because 'in the course of so many ages there has been so great a dearth and barrenness of arts and inventions'. In this aphorism, then, Bacon outlines a kind of philosophy of history according to which certain constituent and original discoveries took place in the primordial phase of human history, partly due to science but in large measure to chance and circumstances; these discoveries then

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[8] Cipolla C.M., *Le macchine del tempo. L'orologio e la società (1300–1700)* (Bologna: 1981) 19–20 and 115–118; Landes D.S., *Revolution in time: clocks and the making of the modern world* (Cambridge: 1983). Trad. it. *Storia del tempo. L'orologia e la nascita del mondo moderno* (Milan: 1984) 366–381.

acquired their current degree of refinement thanks to human labour. However, this human industry occurred over a vast time span and only led to improvements rather than producing anything new. Therefore it is responsible for, or at least fully implicated, in the centuries of dearth and barrenness of the arts and of discoveries (*rerum et inventorum penuria et sterilitas*) and in the specular illusion of wealth.

Obviously I am not interested here in pointing out the gaps in Francis Bacon's historical knowledge, but in the fact that he builds a paradigm according to which human 'patience' and the 'subtle and ruled motion of the hand and instruments' are in reality jointly responsible for the extreme slowness, or rather the stagnation, of technical and scientific advancement. Yet – and this is something I will return to later – the notions of perfectibility and invention, understood not as 'illumination' but as something 'added', as a perfecting, were (and will continue to be for a long time) much more closely linked to *patience* than to the investigation of the *axioms* of nature.[9]

A similar position can be discerned in *The Advancement of Learning*, where Bacon introduces the task of a history of mechanics:

> For History of Nature Wrought or Mechanical, I find some collections made of agriculture, and likewise of manual arts; but commonly with a rejection of experiments familiar and vulgar. For it is esteemed a kind of dishonour unto learning to descend to inquiry or meditation upon matters mechanical, except they be such as may be thought secrets, rarities, and special subtleties;[10] [...] But if my judgement be of any weight, the use of History Mechanical is of all others the most radical and fundamental towards natural philosophy; such natural philosophy as shall not vanish in the fume of subtile, sublime or delectable speculation, but such as shall be operative to the endowment and benefit of man's life. For it will not only minister and suggest for the present many ingenious practices in all trades, by a connection and transferring of the observations of one art to the use of another, when the experiences of several mysteries shall fall under the consideration of one man's mind; but further it will give

[9] On the concept and role of *axioms* in Bacon's philosophy of science, see Hesse M., "Francis Bacon's Philosophy of Science", in *Essential Articles for the Study of Francis Bacon*, ed. B. Vickers (Handen: 1968) 124–132.

[10] According to Vickers (Bacon, *The Major Works* 613), the meaning of *collections* is *summaries.* But it could be a reference to collections of mechanical objects or models. Rossi (Bacone, *Scritti filosofici* 205) translates *experiments* into Italian as *esperienze*, but this translation is perhaps somewhat doubtful.

> a more true and real illumination concerning causes and axioms than hitherto attained.[11]

To summarize, a history of mechanics is viewed here partly as a means of transferring technical know-how, but above all as a useful collection of cases for the study of 'causes and axioms': these are the final goal. Bacon does not really take into account the value and weight – and the further possibility – of an autonomous development of the history of mechanics by its own procedures, which are not strictly describable in terms of the application of 'causes and axioms'. In fact, Bacon writes, these are 'the two parts of natural philosophy, the Inquisition of Causes, and the Production of Effects: Speculative, and Operative; Natural Science, and Natural Prudence'.[12] The second follows the first.

Naturally this point in Bacon's argument can also be read as a simplification of his fundamental intent, namely to position (or reposition) technical progress on the foundations of scientific research into the forces of nature. But this is just the point. In the conceptual framework of the *Novum Organum*, this sometimes has little to do with the idea of 'perfectibility' and perhaps something to do with the idea of 'revolution'.

Indeed, when Bacon tries to outline a historic sketch of the development of the sciences, he talks explicitly about 'revolutions' and not about continual, progressive development. In fact, he writes that just six of the twenty-five centuries of human existence have been fruitful for the progress of the sciences, those that correspond to the only three revolutions and periods of the sciences.[13]

It seems to me that Bacon's use of the word *revolutio* in the context of this aphorism is closer to the modern notion of 'progressive movement', and, in some measure, of disruptive, radical 'change', rather than to the ancient and medieval concept of 'cyclic movement',[14] though Bacon was also familiar with the latter.[15]

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[11] *Collected Works of Francis Bacon*, vol. III, part I, 332; Bacon, *The Major Works* 177–178.

[12] *Collected Works of Francis Bacon*, vol. III, part I, 351; Bacon, *The Major Works* 193.

[13] "Nam ex viginti quinque annorum centuriis, in quibus memoria et doctrina hominum fere versatur, vix sex centuriae seponi et excerpi possunt, quae scientiarum feraces earumve proventui utiles fuerunt. Tres enim tantum doctrinarum revolutiones et periodi recte numerari possunt: una apud Graecos; altera, apud Romanos; ultima, apud nos, occidentales scilicet Europae nationes", NO I, 78.

[14] For this distinction, see Bobbio N., 'La rivoluzione tra movimento e mutamento', *Teoria Politica* 2–3 (1989) 4.

[15] In any case, the word 'revolution' has a limited use in the *Novum Organum*. According to Fattori M., *Lessico del "Novum Organum" di Francesco Bacone* I, 440, it is only used

Each of these periods of intellectual revolution – Bacon writes – lasted about two centuries. The first took place with the Greeks, the second with the Romans and the third *apud nos*, that is with the peoples of Western Europe (NO, I, 78). The intermediate periods, for instance those of Arabian culture and of Scholasticism, were not, in his view, productive. It will be noted here that with this periodization, Bacon broadly speaking dates the beginning of his own epoch to the first half of the fifteenth century. Moreover, the discrimination of the Arabic and Christian medieval period in favour of Antiquity is a typical paradigm of Humanism and the Renaissance.

One might of course point out that the difference between advancement in the sciences – which has occurred so far, as it were, during periods of revolution – and the continual, progressive advancement of the mechanical arts is actually the hiatus that Bacon sought to fill with his reform of knowledge, by giving systematicity and method to scientific investigation, so that it too might progress in a continual fashion like technics. Undoubtedly, this is at least partially what Bacon wanted to do.

But in other aphorisms Bacon speaks out clearly in favour of beginning afresh from the foundations rather than proceeding through a process of gradual accumulation. For instance, he writes: 'It is idle to expect any great advancement in science from the superinducing and engrafting of new things upon old' (NO, I, 30–31). And in *The Advancement of Learning*, where he explains the concept of *natural prudence*, or *the part Operative* of Natural Philosophy, he writes:

> For many operations have been invented, sometimes by a casual incidence and occurrence, sometimes by a purposed experiment: and of those which have been found by an intentional experiment, some have been found out by varying or extending the same experiment, some by transferring and compounding divers experiments the one into the other, which kind of invention an empiric may menage. Again, by the knowledge of physical causes there cannot faile to follow many indications and designations of new particulars, if men in their speculation will keep one eye upon use and practice. But these are but coastings along the shore, 'premendo littus iniquum': for it seemeth to me there can hardly be discovered any

twice; the first time in the already quoted aphorism I, 78; and the second, with a different meaning, in aphorism I, 92: 'Itaque existimant [viri prudentes] esse quosdam scientiarum, per temporarum et aetatum mundi revolutiones, fluxus et refluxus'. In the context of this whole aphorism the concept of revolution as cyclic movement is explicitly opposed to that of *progressus scientiarum*.

> radical or fundamental alterations and innovations in nature, either by the fortune and essays of experiments, or by the light and direction of physical causes.[16]

Elsewhere in the *Novum Organum* there is also confirmation of Bacon's fondness for the notion of discovery as a clear break rather than a perfecting process. In the mechanical arts, in fact, he writes, things are passed off as new discoveries when in fact they are not: finishing off works that have already been realized, embellishing them, putting them together and assembling them, relating them more adequately to the use to which they have to be put, making them bigger or smaller than normal, and so on (NO, I, 88). It might seem that these lines from *Novum Organum* are a protest against the age-old habit of boasting about one's achievements. But in the context of the aphorism, the contrast he makes between these practices, which are defined as 'trifling and puerile', and his enthusiasm for discoveries stemming from experimentation and the observation of nature, indicates a strong disdain for, or at any rate a tendency to downplay, the 'normal' method of proceeding in technics. Indeed, this is something that Diderot grasped and described very well more than a century later.

It is well known that Diderot admired the work of the Lord Chancellor, whose classification of sciences was an inspiration for his *Prospectus*, and for the 'Systéme des connaissances humaines' at the beginning of the *Encyclopédie des sciences et des arts*.[17] However, it is worth comparing the previously quoted pages from *Novum Organum* with a page from the *Encyclopédie* article, written at the last moment in 1755, in which Diderot displayed a clear understanding of the working method of the mechanical arts in terms both of its specific reality and its historic importance:

> Mais il n'est pas de l'origine et des progrés d'un art ainsi que de l'origine et des progrés d'une science. Les savants s'entretiennent; ils écrivent; il font valoir leurs découvertes; ils contredisent; ils sont contredits. Ces contestations manifestent les faits et constantent les dates. Les artistes au contraire vivent ignorés, obscurs, isolés; ils font tout pour leur interêt, ils ne font presque rien pour leur gloire. Il y a des inventions qui restent dès siècles entiers renfermées dans une famille: elle passent des pères aux enfants, se perfectionnent ou dègénèrent, sans qu'on sache précisément ni à qui,

[16] *Collected Works of Francis Bacon*, vol. III, part I, 361; Bacon, *The Major Works* 201.

[17] Denis Diderot, *Œuvres*, vol. I, *Philosophie*, ed. L. Versini (Paris: 1994) 211–237.

> ni à quel temps il faut en rapporter la découverte. Les pas insensibles par lequels un art s'avance à la perfection, confondent aussi les dates. L'un recueille le chanvre; un autre le fait baigner; un troisième le tille; c'est d'abord un corde grossière; puis une fil; ensuite une toile: mais il s'écoule un siècle entre chacun des ces progrès. Celui qui porterait un production depuis son état naturel jusqu'a son emploi le plus parfait, serait difficilment ignoré. Comment serait-il impossibile qu'un peuple se trouvât tout à coup vêtu d'une etoffe nouvelle, et ne demandât pas à qui il en est redevable? Mais ces cas n'arrivent point, ou n'arrivent que rarement.
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> Communément le hasard suggère les premières tentatives: elles sont infructueusses et restent ignorées. Un autre les reprend: il a un commencement de succés, mais dont on ne parle point; un troisième marche sur le pas du second; un quatrième sur le pas du troisième; et ainsi de suite, jusq'a ce que le dernier produit des expériences soit excellent; et ce produit est le seul qui fasse sensation.[18]

Diderot is well aware that the sciences occupy a significant position in the phenomenology of practical mechanics,[19] but he is equally conscious that the logic of the advancement of learning in the sciences is very different from the logic of those whom he calls artists (*les artists*), who here are essentially artisans, or, to use the word in its archaic sense, mechanics. Diderot also clearly recognizes that the development of the mechanical arts was achieved by means of incremental modifications in the course of very slow and by no means irreversible processes. He does not regard this as negative, and he does not regard it as being secondary or additional to the moment of discovery. Far from it. Diderot talks explicitly of inventions (*inventions*) that arose from and were perfected within the framework of technical procedure (or at least to a significant degree). Invention (*invention*) is not, then, at odds with the imperceptible pace (*pas insensibile*) of the arts. And it is significant that as an example of this mode of technical progress he cites the processing of hemp from raw material to woven fabric, a typical example from the world of production, in particular the manufacturing world.

There is also an important indication of the use of a cluster of concepts akin to that of revolution in Bacon's theory of discovery (*inventum*) as direct recourse to the sources of reality (*fontes rerum*), that is nature and its properties; discovery is a break with the customary, with the known, with what is handed down (*multa ex his quae ex fontibus rerum petuntur per rivuolos consuetos non fluant*), which, by contrast, represents an

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[18] *Encyclopédie*, in Diderot, *Œuvres*, vol. I, *Philosophie* 427.
[19] Ibid., 425.

obstacle to discoveries (NO, I, 109). It is worth looking at the examples he gives of such breaks: artillery, silk thread, the compass. The argument he uses to describe the revolutionary novelty of artillery bears careful examination. To illustrate the virtues of an instrument for destroying walls and fortifications from a distance, traditional science would have got us to imagine a force to be multiplied by weights, wheels, thrust and collision devices, but not a wind of fire, a magnificent phenomenon of nature similar to an earthquake or lightning.

In these few, effective words, Bacon is in actual fact clearly departing from the whole ancient and Renaissance tradition of mechanics as essentially the science of statics. He then moves on to talk about the compass; its essential characteristic, in his view, is not that it is a more sophisticated construction of astronomical instruments, but the substance of the stone or metal from which it is made (*substantia lapidea aut metallica*). As for silk thread, Bacon focuses exclusively on the almost incredible fact that thread can be produced, ready for use, by a small worm. He does not even consider, for example, innovations such as the silk mill, which proved decisive in the development of silk weaving and which marked a giant leap forward in the mechanization of the manufacturing process.

We have seen that Bacon includes the period in which he is living in a new age that had already been underway for two centuries, and which thus began in the first half of the fifteenth century. It is worth comparing the reasoning of the *Novum Organum* with some passages from Angelo Poliziano's *Panepistemon*,[20] a genuine encyclopaedia of the sciences and arts in Florence at the time of Lorenzo the Magnificent. This encyclopaedia already gave mechanics a singular primacy with respect even to the fine arts and architecture. The machine for Poliziano is a kind of 'sensational expedient' that develops within *poiesis*, creative activity, an activity that involves above all the construction of traction and hydraulic machines, and which is not fundamentally about the discovery and domination of the forces of nature. For Bacon, on the other hand, technical invention is the discovery and subjection of previously unheard-of natural forces – the *ventus igneus* of the cannon or

[20] Nanni R., "La tecnica nel 'Panepistemon' di Angelo Poliziano: mechanica e artes sellulariae", *Physys* 3 (2007); and Nanni R., "Le 'Panepistemon' d'Ange Politien et Léonard de Vinci. Images des arts mécaniques et technique textile en Italie entre XV[e] et XVI[e] siècle", in Brioist P. – Dolza L. – Verin H. (eds.), *Les Machines à la Renaissance* (Brepols: 2008).

the *substantia lapidea aut metallica* of the compass. Textile manufacturing techniques themselves, as we have seen, are read and subsumed within this kind of 'naturalistic' paradigm. In this respect Bacon is a child of his age. He clearly grasps the huge implications of some of the most sensational inventions and discoveries of his age. But this somehow makes invisible to him a world of machines that had been in existence for centuries, and which at the time was the object of a widespread transfer of knowledge between France and England, through the circulation of both technical manuscripts and printed *theatri machinarum*.[21] It was a world which, before the harnessing of steam, advanced principally though not exclusively by making improvements to components and through kinematic inventions such as the crankshaft for transforming rotating motion into alternating motion, or the pendulum pump, modifications to which started in Taccola's time and continued through to Newcomen's steam engine. These inventions were more the result of a slow process of perfecting than of a marked break.

Proof of this situation comes from Bacon himself, when he affirms that bodies in the mechanical arts are altered in particular through instances of composition or separation (NO, I, 66). It is quite evident that this definition of the mechanical arts tends to assimilate them more to processes of fusion or self-transformation of the products of nature (as happens, for example, with wine), rather than to mechanics. This conception of the mechanical arts results in a specific view of technics as something that is associated with experimentation and the manipulation of the physical and chemical properties of bodies rather than with the design and construction of mechanisms, in the development of which the accrual of sometimes imperceptible modifications to components and their assembly in kinematic chains has been historically more important.

One might almost say that there is a thin but unbroken thread of continuity running from the ancient definition of Vitruvius[22] through

[21] Cf. Brioist P., "Les livres de machines entre France et Angleterre (1560–1680)", in Genet J.P. – Ruggiu F.J. (eds.), *Les idées passent-elles la Manche?* (Paris: 2007) 145–160. See Dolza L. – Verin H., "Figurer la mécanique: l'énigme des théatres de machines de la Renaissance", *Revue d'Histoire moderne et contemporaine* 51–2 (2004) 7–37, for an updated survey of the problems associated with this kind of literature.

[22] Vitruvius, *De Architectura*, ed. P. Gros (Turin: 1997) II 1300: 'Machina est continens e materia coniunctio maximas ad onerum motus habens virtutes' (L. X, 1).

to the definition of a machine given by Franz Reuleaux[23] in the second half of the nineteenth century in his seminal work on kinematics. The essential feature of the machine, according to this tradition, is that it is a collection of resistant bodies in movement, a feature which also serves as the basis for the study of machines.

It is not surprising that Hermann Grothe, Reuleax's student, complained in 1874, in one of the first German (and European) studies on Leonardo, that Reuleaux had been unable to examine Leonardo's manuscripts, because if he had he would have had no difficulty in seeing that the practice of breaking down machines into individual parts and considering them in their own right started long before Leupold.[24] In any case, this aspect of mechanics seems broadly speaking to be extraneous to Bacon's vision of technics.

Indirect confirmation of this conceptual framework can also be found by comparing the use of the words *inventio* and *inventum* in the *Novum Organum* with that of *ingenium*.[25] The latter is usually employed with the generic meaning of the 'faculty of the human mind'. Only once, in NO, II, 31, *ingenia*, are those works also defined as *Manus hominis*, that is to say 'opera (hominis) maxime nobilia et perfecte' in each art, a meaning which references the medieval and Renaissance notion of engineering invention.[26] In the context of the aphorism, Bacon displays for these *ingenia* his usual attitude of appreciation infused with historical *pietas* and a basic, underlying devaluation. On the other hand, *inventio* and *inventum* are always associated with discoveries of causes and axioms: 'ex omnimoda experientia, primum inventio causarum et axiomatum verorum elicienda est', Bacon writes in NO, I, 70. And, he affirms in the *Distributio operis* of the *Instauratio magna*, it is known that the 'axiomata recte inventa' can only be derived from 'tota agmina operum'.[27]

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[23] Reuleaux F., *Kinematics of Machinery* (London: 1876) 35, 'A machine is a combination of resistant bodies so arranged that by their means mechanical forces of nature can be compelled to do work accompanied by certain determinate motions.' A book by F.C. Moon, entitled *The Machines of Leonardo da Vinci and Franz Releaux. Kinematics of Machines from the Renaissance to the 20th Century* (Dordrecht: 2007) was published while the present study was being completed, and I have not yet been able to consult it.

[24] Grothe H., *Leonardo Da Vinci. Erfinder und Konstrukteur* (Leipzig: 2003; first edition: *Leonardo da Vinci als Ingenieur und Philosoph. Ein Beitrag zur Geschichte der Technik und der Induktiven Wissencshaften* (Berlin: 1874) 71.

[25] Fattori, *Lessico del "Novum Organum" di Francesco Bacone* 263–64 and 241–242.

[26] See Verin H., *La gloire des ingénieurs. L'intelligence technique du XVI^e au XVIII^e siècle*, 19–22, for an analysis of these two meanings of *ingenium*.

[27] *Collected Works of Francis Bacon*, vol. I, part I, *Philosophical Works* 141. An interpretation parallel to mine, though expressed in a different context, can be found in Pérez-

It would be interesting to compare Bacon's use of these concepts with the image of the 'inventeur d'un mécanisme' as a new discoverer of the machines of the Ancients – an image inherited from High Renaissance literature and put in circulation through the works of figures like Ceredi, Besson and Vivès.[28] In any case, Bacon's idea of invention is far removed from that which can be found, for example, at the end of fifteenth century in Luca Pacioli's *De Divina Proportione*, in which the meaning of inventions was mainly if not exclusively 'inventioni de machine'.[29]

Finally, let's look once again at Bacon's notion of 'invention', at the point where he lists the three contemporary 'mechanical discoveries' that, together with the geographical ones (NO, I, 84), changed the face of the world and the conditions of life on earth: the art of printing (to which Bacon alludes only briefly), gunpowder and the compass. This is not the place to question whether the word 'discovery', as used by Bacon, is really appropriate with regard to the compass.[30] Suffice it to note that in Bacon's view these discoveries changed everything in letters, in the art of warfare and in navigation (NO, I, 129). Bacon lived through the long age of these sensational epochal discoveries, and was fully aware of their significance. He was aware of their spectacular nature. Perhaps he also saw their unrivalled rhetorical persuasiveness and exceptional visibility; this is also due to the much greater social visibility of letters, warfare and the great voyages of exploration in

Ramos A., *Francis Bacon's Idea of Science* (Oxford: 1988) 149: '*Opera* and "works" do not designate *artificialia* as such, but the result of any such operations and the operations themselves which are purportedly guided by theoretical knowledge or, alternatively, lead back to it. It may well be that in some cases the re-instantiation of Nature's effects – of the qualities of things our phenomenal world is made of – is conducive to the construction or fabrication of *artificialia* like the mariner's compass or the lightning-rod if magnetism or electricity are the objects of enquiry. But it is important to notice that it is only at this further stage that an artefact comes in; on this interpretation, the scope of human knowledge becomes a praxiology, a set of rules of successful operation which *sometimes* can be translated into the terms of a particular technique. The class of objects-to-be-known in Baconian science turns out to be the class of objects to be brought about through human agency – taking the word "object" (*res*) in its widest possible sense. To repeat the formulation suggested in Part II: "Vere scire est [per causas] producere posse".'

[28] Dolza L. – Verin H., "Figurer la mécanique: l'énigme des théatres de machines de la Renaissance" 15–17.

[29] Luca Pacioli, *De Divina Proportione* (Milan: 1956) 10.

[30] See Johnston S., "Theory, Theoric, Practice: Mathematics and Magnetism in Elisabethan England", *Journal de la Renaissance* 2 (2004) 53–62, for a survey and a new attempt to look at the history of the discovery, understanding and application of magnetism.

comparison to manufacturing and its technology. This at any rate is the aspect of technical development that he sees most of all, and he rhetorically models his notion of invention and progress on the sensational nature of the discovery, on his *vis, virtus* and *consequentia rerum*, as he himself writes (NO, I, 129).

In conclusion, then, I believe that in addition to the phenomenology of mechanics and the idea of perfectibility inherent to it, and to the consequent notion of knowledge as cumulative, Francis Bacon gave an important role in his model of the reform of knowledge to the notion of a break with the scientific and cultural tradition in general, viewing invention only as the discovery and manipulation of the properties of nature, and sometimes also as something spectacular. Finally, all this is coherent with the main purpose of his intellectual engagement. Mary Hesse, reacting to the image of the Lord Chancellor as an empiricist and almost as a simple fact-collector, writes:

> His projected life-work was the Great Instauration, which was to lay the foundations of the science entirely anew, sweeping away all received notions, returning to a fresh examination of particulars and proceeding from them by an infallible method to axioms of greater and greater generality, and then descending by deduction to new particulars and useful operations upon matter. The work was to correct on the one hand the excessive rationalism of the ancient philosophers, who leaped straight from particulars to ill-founded general axioms and then reasoned only by syllogism, and on the other hand it was to correct the unregulated empiricism of the alchemists and natural magicians, who wasted their time in unfruitful experimenting, and lit upon true discoveries only by accident. Bacon, by his method of inducing general axioms, intends to establish 'a true and lawful marriage between the empirical and the rational faculty'....[31]

If this was the goal and the essential impulse of Bacon's life-work – that is to say to establish a new *science*, though operative –, I think it would be justified and useful, starting from the problematic aspects I have tried to outline, to investigate his entire work in order to establish whether he perhaps misunderstood some significant aspects of the reality of technical knowledge and the procedures by which it developed.

[31] Hesse M., "Francis Bacon's Philosophy of Science" 115.

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THE WEATHERGLASS AND ITS OBSERVERS IN THE EARLY SEVENTEENTH CENTURY

Arianna Borrelli

Introduction: The Inverted-Glass Experiment

Air expands when heated and contracts again when it cools down. This phenomenon plays a very important role in the science of weather and climate, because it is the sun's heating power which sets in motion the air masses of the Earth's atmosphere.[1] The thermal expansion and contraction of air can also be used to estimate variations in temperature, and the earliest thermometers, developed at the beginning of the seventeenth century, were based precisely on this principle.[2]

These early devices, which can be described as non-sealed air-thermometers, are the subject of the present paper. My goal, here, however, is not to discuss anew the origin of the thermometer nor to address the question of who invented it. Instead, I plan to investigate the factors which brought this specific experimental set-up to the attention of

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[1] Newton D.E., "Wind", in Newton D.E., *Encyclopedia of air* (Westport: 2003) 208–213 esp. 209–210; Häckel H., *Meteorologie* 301–303.

[2] Particularly useful for the subject dealt with in this paper are some older publications on the origin of the thermometer: Caverni R., *Storia del metodo sperimentale in Italia*, vol. 1 (Firenze: 1891); Hellmann G., "Beiträge zur Erfindungsgeschichte meteorologischer Instrumente", *Abhandlungen der preussischen Akademie der Wissenschaften, phys.-math. Klasse*, 1 (Berlin: 1920); Wohlwill E., "Zur Geschichte der Erfindung und Verbreitung des Thermometers", *Annalen der Physik*, 124 (1865) 163–178; Wohlwill E., "Neue Beiträge zur Vorgeschichte des Thermometers", *Mitteilungen zur Geschichte der Medizin und der Naturwissenschaft*, 1 (1902) 5–8, 57–62, 143–158, 282–290. The most recent publicaton on the origin of the thermometer and the question of its inventor or inventors is: Taylor F.S. "The origin of the thermometer", *Annals of science*, 5 (1942) 129–156. Other monographies on the general history of thermometers and of the modern concept of temperature are: Bolton H.C., *Evolution of the thermometer 1592–1743* (Easton PA: 1900); Burckhardt F., *Die Erfindung des Thermometers und seine Gestaltung im XVII. Jahrhundert* (Basel: 1867); Golinski J., "Barometers of change: meteorological instruments as machines of enlightenment", in Clarck W. – Golinski J. – Schaffer S. (eds.), *The sciences in Enlightened Europe* (Chicago: 1999) 69–93; Golinski, J., "'Fit instruments': thermometers in eighteenth-century chemistry", in Holmes F.L. – Levere T.H. (eds.), *Instruments and experimentation in the history of chemistry* (Cambridge MA: 2000) 185–210; Middleton W.E.K., *A history of the thermometer and its use in meteorology* (Baltimore: 1966); Renou E., *Histoire du thermomètre* (Versailles: 1876).

natural philosophers, eventually lending it such significance that it at times rivalled that of weight-driven clockworks.

The starting point of my discussion is an anonymous experiment in natural magic involving air, water and fire, as well as a glass vessel. It was first described by Giovanni Battista Della Porta (ca. 1535–1615) in his *Four Books of natural magic* (1558), and I shall refer to it as 'the inverted-glass experiment'.[3] The experiment consists in the following steps: (1) take an empty (i.e. air-filled) glass flask with a long neck, (2) heat it up, (3) turn it upside down, (3) plunge the extremity of its neck into a bowl full of water. After a while, as the air in the flask cools down, (4) observe the water in the bowl slowly rise up the neck of the inverted glass flask. The explanation of the phenomenon is that water rises as the air in the glass cools down and thus contracts.

The fact that air expands when heated, moving objects which stand in its way, had been known since antiquity. Devices based on this effect are described in the writings on pneumatics by Philo of Byzantium (c. 200 BC) and Hero of Alexandria (c. 62 AD).[4] This knowledge was passed on first to Arabic-Islamic scholars and craftsmen, and later to Renaissance engineers, who were particularly skilled in developing fountains based on both pneumatic and hydraulic effects.[5] However, the idea of making the phenomenon of expansion and contraction of air visible through glass seems to have occurred for the first time only to late Renaissance experimenters. This may be due in large part to the ready availability of glass vessels of all forms, used in alchemical experiments.

In the following pages, we shall follow the transformation in form and natural philosophical significance of the inverted-glass experiment

[3] Della Porta G.B., *Magiae naturalis sive de miraculis rerum naturalium libri IIII* (Anverse: 1560) 59r. All my references are made to the 1560 Anverse edition of this work. As Laura Balbiani has shown, the textual differences between the various editions are negligible. Balbiani L., *La 'magia naturalis' di Giovan Battista Della Porta. Lingua, cultura e scienza in Europa all'inizio dell'età moderna* (Bern: 2001) 23.

[4] For a brief overview on Philo's and Hero's work with further references, see Tybjerg K., "Hero of Alexandria's mechanical treatises: between theory and practice", in ed. A. Schürmann, *Geschichte der Mathematik und der Naturwissenschaften 3: Physik/Mechanik* (Stuttgart: 2005) 204–226. On the influence of Heron's Pneumatics see: Boas M., "Hero's Pneumatica: a study of its transmission and influence", *Isis*, 40 (1949) 38–48.

[5] Hollister-Short G., "The formation of knowledge concerning atmospheric pressure and steam power in Europe from Aleotti (1589) to Papin (1690)", *History of technology*, 25 (2004) 137–150; Prager F.D., "Fontana on fountains", *Physis*, 13 (1971) 341–360; Schmeller H., *Beiträge zur Geschichte der Technik in der Antike und bei den Arabern* (Erlangen: 1922) 26–27.

from 1558 until the late 1620s, i.e. until that experimental set-up came to be regarded by many as an instrument to measure degrees of heat and cold. In the 1620s, the device was given a name which summed up its function: thermometer. As we shall see, though, the measure of heat and cold was only one side of a rather complex story, in which the technical artefact called "thermometer" could also be regarded as a perpetually moving weatherglass, demonstrating the activity of air and helping predict the weather.

Due to the set-up of the inverted-glass experiment, it is fully capable not only of measuring degrees of heat and cold, but also of remaining in perpetual motion and of responding to weather changes as well, sometimes even in advance. Because the water bowl is open to the atmosphere, the height of the water column varies according not only to temperature, but also to external air pressure. As I shall argue, in the crucial, initial phase, it was the capability of making visible the activity of air which made the set-up interesting both for natural philosophers and for a wider audience.

As I shall endeavour to show in the following pages, this interest grew partly out of a heightened attention to weather phenomena, and partly out of a renaissance of philosophies of nature in which "spirit" or "spirits" acted as a medium between the corporeal and the incorporeal world. In this context, the inverted-glass experiment was seen as a demonstration of a new, anti-Aristotelian theory of the origin of winds. It did so by showing how air, when heated, could acquire moving force. Shortly afterwards, versions of the inverted-glass experiment enjoyed a remarkable popular success as "perpetua mobilia", since the water in the glass moved slowly but incessantly without any apparent mechanical cause.

Later, the device's reactions to temperature changes became its prominent feature in the eyes of philosophers belonging to some specific schools of thought, notably both the Aristotelian Jesuits and the anti-Aristotelian friends and heirs of Galileo Galilei (1564–1642). However, those who followed another non-Aristotelian view of nature, namely that characterized by Allen Debus as 'chemical philosophy', continued seeing in the inverted-glass experiment visual proof of the holistic connection between microcosmos and macrocomos.[6]

[6] On chemical philosophy: Debus A.G., *The chemical philosophy: Paracelsian science and medicine in the sixteenth and seventeenth centuries*, 2 vols (New York: 1977).

Thus, the history of the weatherglass/thermometer provides an example of how the same technical artefact can acquire different meanings according to the philosophical framework of those approaching it. Yet this is not all. Studying the history of the inverted-glass experiment also offers an overview of the many ways in which philosophers and technological artefacts could come into contact with each other in the early modern period. The inverted-glass experiment was for some simply a literary description in Della Porta's widely read *Four books on natural magic*. Yet there is no doubt that that experiment was also being carried out by some interested readers. Similar set-ups were also exhibited as marvels at courts or fairs, and those who could not attend the shows in person would perhaps see the artefact in sketches done by travellers. Some "virtuosi", having seen or heard of the device, actually built a replica of it.[7] Had they been unable to do so, they might have bought a copy: already in the 1620s, weatherglasses/thermometers were being produced and sold for profit. Finally, the popularity of such devices could be exploited by natural philosophers to make their own worldview accessible and acceptable to a broad public. In 1631, Robert Fludd (1574–1637) chose the weatherglass, by then a well-known instrument, and used it as a form embodying the whole of his cosmology.

Giovanni Battista Della Porta's Four books on natural magic *(1558): A Marvel of Glass, Water, Fire and Air*

In his psychological portrait of Giovanni Battista Della Porta, the historian Mirko Grmek writes:

> There is something deeply tragic in the scientific work of Della Porta. For historians of science, the Neapolitan scholar is a man of missed opportunities. [...] It is only in retrospective, looking back at the events, that one notices how Della Porta was lucky in the choice of certain subjects for his investigations, but unlucky in the their final outcome. We may take as an example magnetism, the thermometer, the camera obscura and the telescope.[8]

[7] On early modern "virtuosi", see: Eamon W., *Science and the secrets of nature. Books of secrets in medieval and early modern culture* (Princeton: 1994) 301–318.

[8] 'Il y a quelque chose de profondément tragique dans l'oeuvre scientifique de Della Porta. Pour les historiens des sciences, le savant neapolitain est un homme d'occasions

While it is true that Della Porta was often among the first to describe new technological devices, without ever being credited with their invention, there is another, less tragic, way of looking at his work, namely seeing it as a privileged research ground to study the changing relationship between philosophy and technology in the early modern period.

Giovanni Battista Della Porta was born approximately in 1535 to a noble but impoverished Neapolitan family, whose members cultivated a deep interest in classical and natural philosophical studies. He was probably educated privately, by tutors as well as by older members of the family. Already as a child, Della Porta was fascinated by the world of natural magic, both texts and experiments. He did not let financial difficulties stand in the way of his studies, travelling across Italy and Europe and partly financing his own experiments. He was helped by patrons like Federico Cesi (1585–1630). In 1603, Cesi founded the Accademia dei Lincei in Rome, which Della Porta joined in 1610. Della Porta published several works, but the most successful was his *Four books on natural magic* (1558), later expanded into a twenty book edition (1589). He also wrote books on specific issues of natural magic, as well as a number of plays in the Italian language. Significantly, the symbol and motto of the Accademia dei Lincei were taken from one of Della Porta's works. Because of his writings and his fame as a "magus", the Neapolitan author often faced the problem of censorship and likely of the Inquisition as well.

The inverted-glass experiment is described in Della Porta's earliest work, the *Four books on natural magic*, which was printed in its original Latin version in Naples in 1558 and immediately enjoyed success throughout Europe.[9] Between 1558 and 1588 it was reprinted more

manquées. [...] Ce n'est que rétrospectivement, en remontant les événements, qu'on constate combien Della Porta avait de la chance dans le choix de certains sujets de ses investigations et de la malchance dans leurs aboutissements. Prenons comme exemple le magnétisme, le thermométre, la chambre obscure et le télescope', Grmek M.D., "Portrait psychologique de Giovan Battista Della Porta", in ed. M. Torrini M., *Giovan Battista Della Porta nell'Europa del suo tempo* (Neaples: 1990) 17–30, quote taken from p. 27. My discussion of Della Porta's life and work is based on Zaccaria R. – Romei G., "Giambattista Della Porta", *Dizionario biografico degli Italiani*, 37 (1989) 171–182; Eamon W., *Secrets of nature* 195–233; Rienstra M.H., "Giambattista Della Porta", *Dictionary of scientific biography*, 11 (1975) 95–98.

[9] The *Four books on natural magic*, are analysed in their contents, style and influence in Balbiani L., *Magia naturalis*. Balbiani addresses the difficult question of the reception of the work on pp. 78–85 and offers an overview of its many editions and translations (Balbiani L., *Magia naturalis* 212–218).

than fifteen times, for example in Anverse (1560), Lyon (1561), Cologne (1562) and Frankfurt (1585). The book was also translated into Italian (1560), Dutch (1566), French (1565) and German (1612), thus becoming accessible also to a less learned public. The reception of the work, both the positive and the negative one, was not only fast and intense, but also extended to an extremely varied readership. This fact is important for our subject, because it means that the experiments described in the book soon became known to a large, differentiated audience.

The *Four books on natural magic* were a collection of instructions on how to replicate and understand the secrets of nature.[10] According to Della Porta, the aim of natural magic was to replicate and understand the natural causes of marvels, i.e. of natural phenomena which are considered marvels by people who are ignorant of their real causes. Natural magic was, in this sense, 'natural philosophy brought to its highest perfection', and its practitioner, the 'magus', was a philosopher skilled both in performance and explanation of natural marvels.[11]

In the fourteenth chapter of the second book of the *Four books on natural magic*, Della Porta writes:[12]

> No less marvellous is the experiment where, if you want, an inverted vase draws up water.
>
> You shall do it so. Take a vase with a very long neck (the longer the neck is, the more marvellous [the experiment]), made out of glass and transparent, so that you shall see through it the water rise. Fill it completely with boiling water, and so it will become all very hot (or alternatively bring its bottom near to a fire), then immediately, lest it cool down, turn it upside down and put its mouth in the water, and it will absorb it all in itself. The explorers of the nature of things say that it is in this way that water is drawn up and absorbed by the rays of the sun from the caves of the earth in mountains, so that water springs originate. And no few artifices are derived from this in pneumatic machines, as Heron tell

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[10] For a discussion of the scope, and sources of Della Porta's conception of natural magic, see Eamon W., *Secrets of nature* 210–217.

[11] 'naturalis philosophiae consumationem' Della Porta G.B., *Magiae naturalis libri IIII* 1r–1v.

[12] The relevance of this passage for the history of the thermometer was noted by Caverni R., *Storia*, vol. 1 270, and Hellmann G., "Erfindungsgeschichte" 10–11. More recent authors, instead, have failed to mention it: Taylor and Middleton, the latter probably following the former, quote another, similar experiment, which does not involve a glass vessel, and also convey the erroneous impression that Della Porta only dealt with thermal expansion of air in the second edition of the *Natural magic* (1589) (Taylor F.S., "Origin" 133–134; Middleton W.E.K., *Thermometer* 5).

> us, but such things are beyond our purpose, so let us go on to another subject.[13]

Although very concise, Della Porta's description of the inverted-glass experiment is clear, except possibly when he says that the glass vase should be filled with boiling water to make it hot, without specifying that it has to be emptied before plunging its neck into a (cold) water basin. The importance of using a glass vessel, through which the rising water can be observed is underscored. Interestingly, air is not even mentioned in this passage: the only elements explicitly appearing are fire and water. It is the water rising under the influence of fire that is being observed and interpreted as demonstrating how the sun draws up water from earth.

Della Porta does not claim to have invented the inverted-glass experiment himself, and there is no reason to think that he did so. Possibly, he had not even performed it in person, when he wrote the *Four books on natural magic*. Nonetheless, the inclusion of the inverted-glass experiment in his successful book insured it a wide and rapid diffusion in Europe, setting in motion different, parallel processes of reception and reflection on the subject.

Giovanni Battista Benedetti: The Rare, the Dense and the Origin of Winds

A particularly relevant reflection was made by Giovanni Battista Benedetti (1530–1590), mathematician, astrologer and natural philosopher working in Turin at the court of the Duke of Savoy.[14] Benedetti was, before Galileo, the main Italian contributor to the mathematisation of natural philosophy. In 1585, he published a *Book of various mathematical*

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[13] 'Nec admirationis minus extat experimentum, cum voles, ut vas inversum aquam hauriat. Quod sic efficies. Longissimi colli paretur vas, et quo longius fuerit, eo mirabilius, vitreum vero, et pellucidum, ut ascendentem perspicies aquam, hoc bullientis aquae expletur, et ubi totum efferbuerit, vel igni fundum admoveto, illico, ne frigescat, inverso ore aquam tangat, et intro totam absorbeat. Sic naturae rerum exploratores Solis radiis aquam hauriri, et absorberi aiunt, e terrae concavis locis in montibus, unde fontanea efficitur scaturigo. Nec levia insurgunt hinc artificia, in spiritalibus machinis, ut tradit Heron, sed uti ab hoc proposito aliena, alio transferatur.' (Porta G.B., *Magiae naturalis libri* IIII 59r).

[14] On the life and work of Giovanni Battista Benedetti, see: Cappelletti E., "Giovanni Battista Benedetti", *Dizionario biografico degli Italiani*, 9 (1966) 259–265; Drake S., "Giovanni Battista Benedetti", *Dictionary of scientific biography*, 1 (1970) 604–609.

and physical speculations, also containing a collection of critical *Disputations about some of Aristotle's opinions*.[15]

Chapter 34 of the *Disputations* is devoted to 'Some questions on the rare and the dense, which have been discussed by the Peripatetics in a less than correct way'.[16] The chapter dealt with the rarefaction and condensation of various substances, among them air. In full agreement with modern meteorologists, Benedetti explained that winds are caused by changes in the density of the air, which are due in turn to the heat of the sun. Thus, he opposed the view of Aristotle (384–322 BC) according to which winds are not moving air, but are made out of dry exhalations drawn up from the earth by the sun.[17]

> Nor can it be passed under silence that neither Aristotle nor any of his followers noticed that the dense and the rare are the cause of winds. Rare and dense happen through heat and cold and, if it is allowed to argue from the parts, in homogeneous things, to the whole, then everybody can reach the conclusions he prefers when observing that, in the hot days of summer, if some small cloud moves to cover the sun, immediately one can feel there an agitation of the air. And indeed, once the small cloud has gone further, and the air in that place has gone back to the original state of density caused by the sun, [the air] quiets down.[18]

Later in the chapter, Benedetti described the inverted-glass experiment, albeit without explicitly using a glass vessel. He used it to contradict Aristotle's theory of the sun drawing up vapours and exhalations from the earth:

> We can demonstrate this with an experiment taking a vessel filled with nothing but air. If we first heat it up with a fire, and then [put it] with its mouth in a large bowl or some other vessel full of wine or water, we shall see in this way the fluid being immediately sucked up because, as

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[15] Giovanni Battista Benedetti, *Diversarum speculationum mathematicarum et physicarum liber* (Turin: 1585), containing the "Disputationes de quibusdam placitis Aristotelis".

[16] 'De raro et denso nunnulla, minus diligenter a peripateticis perpensa', in Benedetti, *Diversarum speculationum* 191–194.

[17] Gilbert O., *Die meteorologischen Theorien des griechischen Altertums* (Leipzig: 1907) 522–535.

[18] 'Neque silentium involvendum est, nec Aristotelem, neque alium ex suis fautoribus animadvertisse densum et rarum esse causam ventorum. Rarum autem et densum, mediante calore et frigore fit, et si a partibus, in omogeneis, licet argumentari, de toto deducat consequentiam qui velit, observans in calidis aetatis diebus, dum aliqua nubecula ad Solem coperiendum incedit, ibi statim agitationem aeris sentiri, ea vero nubecula praetergressa cum fuerit, et in ea parte, aer ad pristinam raritatem causatam a calore Solis redierit, quiescit.' Benedetti G.B., *Diversarum speculationum* 192.

> the vase heats up, the air contained in it rarefies and, since it rarefies, it expands and, since it expands, it needs more space, and therefore a large part of it goes out [of the vessel]. As that part of air which has remained inside once again condensates, because the heat is gone, it contracts, and needs less space. Things being so, to prevent space from remaining empty, it is necessary that some other body should enter, since it is not possible for air to get in.
>
> Thus, Aristotle was not correct in his meteors, book 1, chapters 9 and 10 and book 2, chapter 2, when he said that it is the heat of the sun which makes exhalations and vapours rise up. [He was wrong] because the sun does nothing but provide heat, and because of this heat, matter rarefies and it is because of rarefaction that it becomes lighter and ascends, and not because it is brought up by the sun.[19]

In this passage, Benedetti criticized an Aristotelian theory of the sun's action similar to that used by Della Porta in his *Four books on natural magic* to explain the inverted-glass experiment, namely that heat attracts water. As we shall see in the following sections, in later publications Della Porta would modify his views on the subject and embrace Benedetti's explanation.

Della Porta's Pneumatics and his Reception of Benedetti

The second edition of *Natural magic* (1589) described the inverted-glass experiment almost with the same words as the first edition.[20] In the Italian translation of his *Three books on pneumatics* (1606), however, Della

[19] 'Idem cum amphora in qua nullum alius, quam aereum sit corpus experiri possumus, si eam ad ignem primo calfactam, deinde cum ore in amplo aliquo cyatho, aut alio vase vino, aut aqua pleno ubi videbimus huiusmodi liquorem statim sursum ferri, quia dum calefit amphora, rarefit quoque aer qui in ea continetur, et quia rarescit dilatatur, et quia dilatatur, eget maiore loco, et ideo magna pars eius foras exit. Cum vero ea aeris portio, quae intus remanserit, iterum condensatur ob defectum caloris, restringitur, minorique indiget loco. Quod cum ita se habeat, necessarium est, ne aliquis locus vacuus remaneat, ut aliud quoddam corpus ingrediatur, cum ad ingrediendum aeri non patuerit aditus. Nec proprie locutus est Aristoteles 9. et 10. capite primi lib. et secundo secundi metheororum cum dixerit calorem Solis eum esse, qui sursum humores, vaporesque evehat, quia Sol nil alius facit, quam calefacere, cuius caloris ratione, ea materia rarefit, et ob rarefactionem levior facta ascendit, non quia sursum a sole feratur.' Benedetti, *Diversarum speculationum* 193–194.

[20] Della Porta, *Magiae naturalis libri XX* (Neaples: 1589) 288.

Porta provides a completely new description of the experiment.[21] The text, accompanied by a drawing, reads as follows:

> Taking an ounce of air which is in its consistence [i.e. stable, in normal atmospheric conditions], one can easily measure in how many parts of finer air it can dissolve. And, although we have already dealt with this subject in our meteors, we do not mind repeating it, since it is appropriate at this point.
>
> Let us take a flask for distillation called "gruale", or popularly named matras, in which one distils "aqua vitae" (i.e. alcohol), as described in our book on distillation. The flask shall be made out of glass, so that the effects of air and water will be visible. This will be vase A, and will have its mouth in a vase B, flat and full of water. That vase [i.e. the first one] will be full of air, which in its consistency shall be more or less thick according to place and season. Then bring a vase full of fire near the body of the vase A: the air, immediately heated up, starts to become more subtle and, once is it made more subtle, it wants more space and, trying to escape, comes out of the water, and one will see the water boil, which is a sign that the air is escaping. The more the air heats up, the more intensely the water boils, but, once the air has become most thin, the water will stop boiling. At that point, remove the vase with fire in it from the belly of A, and the air, cooling down, will become thicker and desire less space and, not having any way to fill the vase because its mouth is under water, will attract the water from the vase, and one shall see the water rise up with great fury, to fill all of the vase, leaving empty only that part where the air lies, reduced back to the nature it had in the beginning.
>
> If you bring once again fire near to that little bit of air, it will again become thinner, and will push down all the water. Taking away the fire, the water shall rise up again. Once the water has stopped rising, mark with pen and ink on the outside of the glass the level of the water surface. Afterwards, letting out all the water from the vase, take another vase and fill the first one with water until it reaches the line you marked with ink. Then measure that quantity of water, and count how many times it has to be taken to fill the whole vase: that is the number of times by which a portion of air, taken at first in its consistence, shall enlarge when it is made more subtle by fire, and from here great secrets take their origin.[22]

[21] Della Porta, *I tre libri de spiritali* (Neaples: 1606). The original Latin version of this work appeared in 1601, but did not contain a description of the inverted-glass experiment.

[22] 'Si può ancora agevolmente misurare un'oncia di aria nella sua consistenza in quante parti di aria più sottile si può dissolvere. E se bene di questo ne habbiamo trattato nelle nostre meteore, pur facendo qui a nostro proposito, non ci rincrescerà di ridirlo. Habbisi un vaso da distillare detto gruale, o volgarmente detto materazzo, dove si distilla l'acquavuite, descritto da noi nel libro di distillare, e sia di vetro, acciò si vedano gli effetti dell'aria, e dell'acqua, e sia il vaso A, questo habbi la bocca den-

I have quoted this description in its entirety, because it is very interesting to compare it with the one Della Porta had given half a century earlier in his *Four books on natural magic*. Though the phenomenon both texts seek to illustrate is essentially the same, the description offered here is radically different, both in style and in content. The older text was very schematic, describing only the essential features of the experiment. The new one offers, instead, at least apparently, a real-to-life description. Moreover, in the new text, air is not only explicitly mentioned, but even becomes the main protagonist of the show, as in Benedetti's work.

As before, particular importance is attached to the use of transparent glass, through which one can see. However, what is being observed now is no longer the water rising and falling, but rather the air expanding and contracting. The vessel is identified as a specific tool used in alchemy, the 'matras', thus presenting the experiment in pneumatics also as an experiment in alchemy.

Della Porta's new description certainly had much in common with Benedetti's, strongly focussing on the expansion and contraction of air. It seems probable that he was influenced by Benedetti's reflections on the original experiment and, in turn, developed them further. However, Della Porta made the most interesting use of the inverted-glass experiment in his book on meteors: *On the transmutations of the air (De aeris transmutationibus)* (1610). Although this work was not published until 1610, it must have already been written by 1606 for, as we have seen, it is quoted in the Italian *Pneumatics*. In Della Porta's meteors, we shall

tro un vaso B, piano, pieno di acqua, il qual vaso sarà pieno di aria, grosso nella sua consistenza, più, e meno, secondo il luogo, e la stagione. Poi accostarete un vaso pieno di fuoco al corpo del vaso in A, e l'aria subito riscaldandosi, si andarà sottigliando, e fatta più sottile, vuole più gran luogo, e cercando uscir fuori, verrà fuori dell'acqua, e si vedrà l'acqua bollire, che è segno che l'aria fugge, e quando si andrà più riscaldando, l'acqua più boglierà, ma essendo ridotta tenuissima, l'acqua non boglierà più, all'hora rimovete il vaso del fuoco dal ventre A, e l'aria rinfrescandosi, s'andrà ingrossando, e vuol minor luogo, e non havendo come riempir il vano del vaso, perchè ha la bocca sotto l'acqua, tirerà à se l'acqua dal vaso, e si vedrà salir l'acqua su con gran furia, e riempir tutto il vaso, lasciando vacua quella parte, dove sta l'aria ridotta già nella sua natura di prima. E se di nuovo accostarete il fuoco a quella poca aria, attenuandosi di nuovo, calerà giù tutta l'acqua, e rimovendo il fuoco, tornerà a far salir tutta l'acqua. Fermata cha sarà l'acqua, voi con una penna, et inchiostro segnarete fuori il vetro l'estrema superficie dell'acqua, poi lasicando uscir fuori tutta l'acqua della carrafa, all'hora con un'altro vaso porrete tanta acqua in detta carrafa, fichè riempirete infin al segno della linea notata con inchiostro: all'hora misurarete quell'acqua, e quante volte quell'acqua riempirà tutta la carrafa, tante volte una parte di aria nella sua consistenza si ampliarà, essendo attenuata dal caldo, e di qua nascono grandissimi segreti.' Della Porta, *Spiritali* 76–77.

find both the inverted-glass experiment and a theory on the origin of winds very similar to the one offered by Benedetti. Before discussing that work, however, I would like to offer a short sketch of the role of meteors and their explanation in late Renaissance Europe.

Meteors in Late Renaissance Europe

Weather phenomena – or rather, meteors – had great importance in late Renaissance Europe, both for the explorers of the secrets of nature and for the broader public of the new medium, the press.[23] While it is well beyond the scope of this essay to discuss the role of meteorology in late Renaissance Europe, a topic which deserves a thorough investigation in its own right, I would like, here, to offer an overview of the subject in order to convey the historical context in which the inverted-glass experiment was able, within a few decades, to gain an extraordinary relevance in natural philosophy. Evidence of the significance of meteorology in the Renaissance includes the growing amount of literature both on weather forecasts and on how to perform them; the popularity of reports and interpretations of extraordinary meteors; a net increase in the number of records of systematic weather observations, as well as in that of treatises explaining meteors, both within and outside of the Aristotelian tradition.

Since the late middle ages, weather forecasts constituted a standard component of the literature offering an overview on major events to be expected in the coming year: astronomical events, religious festivities, seasonal and meteorological changes relevant to agriculture and medicine, as well as political events.[24]

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[23] On early modern meteors and their importance for natural philosophy: Zittel C., "Einleitung", in René Descartes, *Le Méteores/Die Meteore*, ed. C. Zittel, *Zeitsprünge. Forschungen zur Frühen Neuzeit* 10 1/2 (Frankfurt am Main: 2006) 1–28 esp. 1–4.

[24] The following discussion of this kind of literature is based on: Biémont É., *Ritmi del tempo. Astronomia e calendari* (Bologna: 2002) 49–56; Casali E., *Le spie del cielo. Oroscopi, lunari e almanacchi nell'Italia moderna* (Turin: 2003) 35–60 (prognostications in general) and 141–145 (meteorological forecasts); Daxelmüller C. – Keil G., "Prognose, Prognostik", *Lexikon des Mittelalters*, 7 (2002) c. 242–243; Hellmann G., "Wetterprognosen und Wetterberichte des XV. und XVI. Jahrhunderts. Facsimiliendruck mit einer Einleitung", in Hellmann G. (ed.), *Neudrucke von Schriften und Karten über Meteorologie und Erdmagnetismus*, 12 (Berlin: 1899 repr. 1969) 7–26; Maiello F., *Storia del calendario. La misurazione del tempo, 1450–1800* (Turin: 1996) 59–78; Plotzek J.M., "Almanach", *Lexikon des Mittelalters*, 1

According to their contents, these texts can be roughly classified into almanacs, calendars and annual prognostications. Almanacs contained chiefly astronomical information, prognostications concentrated on predicting future events, and calendars listed the religious festivities for the year to come with the corresponding dates. However, by the middle of the sixteenth century a clear-cut distinction between the three types was no longer possible, with all of them often including both a "calendar" in the modern sense and weather forecasts for the coming year. The connection made here between the word "calendar" and weather forecasts, which has since been lost, is significant, for it helps explain the Latin name for the weatherglass: "vitrum calendare".

Calendars, almanacs and prognostications were among the first items to be printed after the invention of the press and, in the course of the sixteenth century, both their volume of production and their variety steadily increased, initially in Italy, later in all of Europe. The earliest printed texts were written in Latin, but soon versions in vernacular languages were produced. From the mid-sixteenth century onward, predictions of political events came to be forbidden by the Catholic Church, but weather forecasts continued to be permitted.[25] Meteorological predictions for the following year were made on the basis of astrological computations, of traditional weather rules, or some combination of both.[26]

The science of astrological weather forecasts, often indicated as "astrometeorology", which had its origin in Antiquity, had been greatly developed in the Arabic-Islamic middle ages, and later passed on to medieval Latin-Christian scholars, who appear to have taken a great interest in it, although they did not apparently employ it for agriculturally relevant predictions. In the Renaissance, all famous astronomers and astrologers published almanacs containing weather prognostications.

In the course of the sixteenth century, not only weather forecasts, but also texts explaining how to perform predictions were printed, both treatises on astrometereology and collections of weather rules. A

(2002) c. 445; Schuster P.-J. – Grams-Thieme M., "Kalender, Kalendarium", *Lexikon des Mittelalters*, 5 (2002) c. 866–867.

[25] Casali E., *Spie del cielo* 61–69.

[26] On astrological weather forecasts and on weather rules, see Bos G. – Burnett C. (eds.), *Scientific weather forecasting in the middle ages. Studies, editions, and translations of the Arabic, Hebrew and Latin texts* (London: 2000) 1–95; Jenks S., "Astrometeorology in the middle ages", *Isis* 74 (1983) 185–210; Maiello F., *Calendario* 49–58. On the combination of the two methods in the Renaissance: Casali E., *Spie del cielo* 142–143.

particularly successful item of the latter kind was the *Bauernpractick*, a booklet published for the first time in Germany in 1508, which saw more than fifty German editions and was soon translated into French, English, Dutch, Danish, Swedish and Norwegian.[27] The *Bauernpractick* explained how to predict the weather for the next year by observing it during the twelve days between Christmas and the Epiphany.

Another constantly expanding kind of printed weather-related material were texts describing or interpreting extraordinary weather phenomena.[28] In particular cases, the growing quantity of printed material could in itself stimulate interest and participation on the part of the public, eventually giving rise to what has been considered as the first media-event in history: the astrological prediction of a Flood for the year 1524, an event which in reality never took place.[29]

While a broad interest in weather predictions and their interpretations was already present in the early sixteenth century, there are indications that, later in the century, meteors started attracting attention also as natural phenomena in themselves, and not simply as a possible danger or as a sign of future events. A growing interest in the systematic observation of weather and an increase in the number of treatises offering a description, classification and explanation of meteors provide evidence of this trend.

Records of systematic weather observations concerning normal meteorological conditions and not only extraordinary events are preserved already from the late middle ages.[30] Those records were apparently kept by scholars engaging in astrological weather predictions. This trend was taken up by Renaissance astrologers like John Dee, and, in

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[27] Hellmann G. (ed.), "Die Bauern-Praktik (1508). Facsimiliendruck mit einer Einleitung", in Hellmann G. (ed.), *Neudrucke von Schriften und Karten über Meteorologie und Erdmagnetismus* 13 (Berlin: 1896 repr. 1969).

[28] Hellmann G., "Wetterprognosen" 21–26; Heninger S.K. jr, *A handbook of Renaissance meteorology with particular reference to Elisabethan and Jacobean literature* (Durham NC: 1960) 23–29; Jankovic V., *Reading the skies. A cultural history of English weather, 1650–1820* (Manchester: 2000) 33–44.

[29] Zambelli P., "Fine del mondo o inizio della propaganda? Astrologia, filosofia della storia e propaganda politico-religiosa nel dibattito sulla congiunzione del 1524", in Garfagnigni G. (ed.), *Scienze, credenze occulte, livelli di cultura. Convegno internazionale di studi* (Firenze: 1982) 291–368.

[30] The following overview is based on: Hellmann G., "Meteorologische Beobachtungen vom XIV. ins XVII. Jahrhundert", in Hellmann G. (ed.), *Neudrucke von Schriften und Karten über Meteorologie und Erdmagnetismus*, 13 (Berlin: 1901 repr. 1969) and Vanden Broecke S., *The limits of influence. Pico, Louvain, and the crisis of Renaissance astrology* (Leiden: 2004) 203–212.

the late sixteenth century, weather observations were part of a program for reforming astrology in Louvain, one of the European capitals of prognostications. According to the historian Steven Vanden Broecke, this activity was not simply aimed at checking the accuracy of astrological predictions, but rather at constructing a 'reformed astrological physics'. Johannes Kepler, too, kept a record of meteorological observations, comparing observed weather and climate with astrological predictions in his defense of a reformed astrology.[31]

Most interestingly, a number of laymen users of calendars and almanacs noted by hand their own weather observations alongside the prognostications or the astronomical data for that date.[32] Systematic meteorological observations were also a relevant part of travellers' reports from the East and West Indies, and their statements, particularly those on tides, very soon found their way into treatises of natural philosophy such as Girolamo Cardano's (1501–1576) *On subtility (De subtilitate)* (1550) and Francis Bacon's (1561–1626) *History of the winds (Historia ventorum)* (1622).[33]

In fact, the European expansion overseas might have contributed to the interest in observing and explaining meteors, both because of the discovery of particularly notable new phenomena, such as the trade winds, and because of the unexpected climatic conditions to which settlers had to adapt, for example in North America.[34]

A general interest in the theory of meteors can also be seen in the increasing number of treatises on the subject which were printed during the late sixteenth and early seventeenth century.[35] Since the thirteenth century, the main reference on the theory of meteors had been the Latin translation of Aristotle's *Meteorology (Meteorologia)*. Soon

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[31] Kepler J., *Tertius interveniens. Warnung an etliche Gegner der Astrologie das Kind nicht mit dem Bade auszuschütten (1610)* (Frankfurt am Main: 2004) 111–112, 207, 251–252.

[32] Hellmann G., "Wetterprognosen" 10.

[33] Nenci E., "Introduzione", in: Girolamo Cardano, *De subtilitate*, ed. E. Nenci, vol. 1 (Milan: 2004) 13–42, here 17–22; Ellis R.L., "Preface to the 'Historia ventorum'", in F. Bacon, *Works*, Spedding J. – Ellis R.L. – Heath D.D. (eds.), vol. 2 (London: 1859, repr. 1986) 1–6, here 4–5.

[34] Laskin D., *Braving the elements. The stormy history of american weather* (New York: 1996) 19–54. A strong case for interest in systematic, instrument-aided weather observations in Virginia is made by Sokol B.J., *A brave new world of knowledge: Shakespeare's 'The Tempest' and early modern epistemology* (Madison-Teaneck: 2003) 111–118.

[35] The following overview is based on Hellmann G., "Entwicklungsgeschichte des meteorologischen Lehrbuches", in Hellmann G. (ed.), *Beiträge zur Geschichte der Meteorologie*, vol. 2 (Berlin: 1917) 1–134 and Heninger S.K. jr., *Renaissance meteorology* 16–23.

after the invention of the press, this work was printed together with commentaries and summaries written both by ancient, medieval and contemporary authors. Around the middle of the century, though, a new kind of treatise on meteors began to appear, namely, books written in the vernacular and explicitly aimed at a lay public. The earliest of them were Italian, for example Cesare Rao's (fl. 1560–1585) *The meteors (I Meteori)* (1582). Other books of this kind were Antoine Mizauld's *Short and easy commentary on all things generated in the air (Brief et facile commentaire de toutes choses engendrée en l'air)* (Lyon 1558), and William Fulke's *A goody gallery with a most pleasant prospect, into the garden of naturall causes of all kind of meteors* (1571). Most of the original works still followed the guidelines of Aristotelian meteorology, explaining phenomena in terms of two exhalations, a humid and a dry one. At times, though, authors rejected some of Aristotle's opinions, quoting alternatives from other ancient authorities.

In the course of the sixteenth century, however, Aristotelian natural philosophy came under attack, especially in its geocentric cosmology and in its strict separation between superlunary and sublunary phenomena. In this context, some philosophers chose to formulate a new, not simply critical, but explicitly anti-Aristotelian theory of meteors.[36] In this category fall Cardano's chapters on meteors in his treatise *On subtility*, Paracelsus' (1493–1541) book *On meteors (De meteoris)* (1566), which was the first meteorology in German, Benedetti's reflections on winds, as well as two works in which the inverted-glass experiment played a central role: Cornelis Drebbel's *Short treatise on the nature of the elements (Een kort tractaet van de natuere der elementen)* (1604) and Della Porta's *On the transmutations of the air* (1610). In 1627, Libert Froidmond (1587–1653) published his *Six books of meteorological matters (Meteorologicorum libri sex)*, a work in which he responded critically to some of the new theories and offered a somehow reformed and updated version of Aristotelian meteorology.[37] His book would become a standard university textbook. Finally, as is well known, in 1637 René Descartes (1596–1650) published his *The meteors (Les Méteores)* as one of the appendixes to the *Discourse on method (Discours de la méthode)* which had the aim of demonstrating the efficacy of his new method of pursuing knowledge.

[36] In Jankovic V., *Reading the skies* 22–24, Jankovic states that sixteenth- and seventeenth-century meteorologies remained essentially Aristotelian. While this statement might be applicable to the late seventeenth century, it certainly does not make justice of meteorology around 1600.

[37] Jankovic V., *Reading the skies* 24.

Apparently, late Renaissance natural philosophers regarded meteors as a field in which to prove their superiority both to the Aristotelian tradition and to their non-Aristotelian competitors, likely as a result of the growing public interest in weather phenomena. After the mid-seventeenth century, however, no new and innovative meteorological treatises were published.[38]

Two additional issues warrant mention at this point, though their relevance as evidence for the general interest in meteors is not indisputable. Firstly, I would point to the appearance of weather phenomena such as rain, dew or snow in literature, theatre plays and sermons, as well as in figurative art.[39] In the early seventeenth century, Dutch landscape paintings were produced, in which weather phenomena like snow and clouds were represented with great care. The latter fact is particularly interesting because, as we shall see, the Low Countries played a very important role in the history of the thermometer.

Secondly, historic climatology tell us that the period between 1570 and 1620 was in average colder than the preceding and following one: it was the so-called "little Ice Age".[40] Though it is difficult to determine the cultural consequences of this phenomenon, it was apparently noted, at least in central and Northern Europe, and might well have inspired the Dutch winter landscapes, as well as heightened the general sensitivity to weather and climate.

The Question of the Origin of Winds

As a further premise to discussing Della Porta's meteors, I would like to make a few general remarks on ancient and modern opinions on

[38] Hellmann G., "Entwicklungsgeschichte des meteorologischen Lehrbuches" 52.

[39] Goedde L.O., "Bethlehem in the snow and Holland on the ice. Climatic changes and the invention of the winter landscape, 1560–1620", in Behringer W. – Lehmann H. – Pfister C. (eds.), *Kulturelle Konsequenzen der 'Kleinen Eiszeit'/Cultural consequences of the 'Little Ice Age'* (Göttingen: 2005) 311–322; Heninger, S.K. jr., *Renaissance meteorology* 153–214; Ossing F., "Der unvollständige Himmel. Zur Wolkendarstellung der holländischen Meister im 17. Jahrhundert", in *Die 'Kleine Eiszeit': holländische Landschaftsmalerei im 17. Jahrhundert. Ausstellungskatalog* (Berlin: 2001) 41–54; Sokol B.J., *Brave new world*; Veit P., "'gerecher Gott, wo will es ihn/Mit diesen kalten Zeiten?'. Witterung, Not und Frömmigkeit im evangelischen Kirchenlied", in Behringer W. – Lehmann H. – Pfister C. (eds.), *Little Ice Age* 283–310.

[40] Behringer W. – Lehmann H. – Pfister C., "Kulturelle Konsequenzen der 'Kleinen Eiszeit'? Eine Annährung an die Thematik", in Behringer W. – Lehmann H. – Pfister C. (eds.), *Little Ice Age* 7–27.

the origin of winds. Pre-socratic philosophers had already stated that wind was nothing but moving air.[41] Aristotle rejected this explanation, arguing that what moved were only dry exhalations drawn up from the earth by the sun. Among the later philosophers voicing a clear opinion on the subject, some agreed with the Stagirit, while others reached back to the older opinion that wind was moving air. Among the latter were the Stoics, in whose cosmology, according to Cicero and Seneca, air played a very important role.[42]

A modern meteorological definition of wind is 'any flow of air'.[43] At the same time, however, winds are recognized as being extremely complex phenomena, for which no general explanation can be offered beyond saying that air moves from a region of higher pressure to one of lower pressure.[44] On a planetary scale, it is the heat of the sun which, by making air expand, sets in motion atmospheric air masses. At the equator, where the maximum heating effect occurs, air rarefies and expands more than in the tropical regions. However, expanding air does not simply push away colder air, but instead, having become lighter, rises up. In this way, a low-pressure area is created around the equator, and colder, thicker air from the tropics rushes in to fill the gap. Thus, as European seamen noted in the sixteenth century, trade winds blow the whole year around from tropical areas towards the equator, both in the northern and in the southern hemisphere.[45] These winds were a mystery for which Edmond Halley (1656–1742) offered an explanation, later refined by George Hadley (1685–1758). Most winds experienced in temperate areas, though, cannot be regarded as resulting directly from thermal expansion, because they are primarily the result of local geophysical structures and the effects of the movement of air masses in tropical areas.

However, even before Halley and Hadley, other natural philosophers had advanced the opinion that winds were caused by the thermal expansion of air under the action of the sun. The first to contend this was the Arabic-Islamic scholar Al-Kindī; the second might have been

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[41] The following overview is basd on Gilbert O., *Meteorologische Theorien* 511–539.

[42] Barker P., "Stoic contributions to early modern science", in ed. M.J. Osler, *Atoms, 'pneuma', and tranquillity. Epicurean and Stoic themes in European thought* (Cambridge: 1991) 135–154, here 138–139.

[43] Newton D.E., "Wind" 209.

[44] The following overview on modern wind theories is based on Häckel H., *Meteorologie* (Stuttgart: 2005) 252–268 and 301–303; Newton D.E., "Wind".

[45] On trade winds, see Fierro A., *Historie de la météorologie* (Paris: 1991) 69–70.

Benedetti.[46] A short time later, the same theory was proposed by Della Porta and by Cornelis Drebbel.

Della Porta's Transmutations of the air *(1610)*

Della Porta's book *On the transmutations of air* (1610) is an anti-Aristotelian treatise on meteors.[47] The work has recently been made accessible in an edition offering details on its large number of references to classical authors. However, its natural philosophical contents have not yet been analysed in detail.[48] While this is not the place for such an analysis, I would like to summarize those statements relevant to the subject at hand.

As we shall see, Della Porta's meteorology was influenced both by Stoic natural philosophy and by contemporary alchemical theories. Moreover, in at least two key questions the Neapolitan philosopher referred to new technological developments. The first was the origin of winds, which I shall discuss presently. The second was the cause of thunder and lightning, which Della Porta identified with explosions of a substance similar to gunpowder.[49] This explanation was offered by Paracelsus and was taken up and expanded by many of his followers, as we shall later see.[50]

For Della Porta, meteors were not simply "changes" in the air, but actual "transmutations" in the alchemical sense: as shown in a table right at the beginning of the book, air could transform itself both into fire and water, thus originating all kinds of meteors.[51]

> Since I am about to write about meteors, it shall be good to start from the air itself, because air completely fills the space between heaven and earth, and contributes matter and basis to all aerial impressions. When it fluctuates, it gives rise to winds, when it is more strongly excited and made thinner, to fire and thunder; contracted, [it gives rise] to clouds, when it becomes thicker, to rain; when it freezes, to snow and when it

[46] Bos G. – Burnett C. (eds.), *Scientific weather forecasting* 345–346.

[47] Della Porta, *De aeris transmutationibus*, ed. A. Paolella (Neaples: 2000).

[48] Purnell F. Jr., "Review of G.B. Della Porta 'De aeris transmutationibus'", *Renaissance quarterly*, 55 (2002) 748.

[49] Della Porta, *De aeris transmutationibus* 148–149.

[50] Debus A.G., "The Paracelsian aerial niter", *Isis* 55 (1964) 43–61.

[51] The transmutations are summed up in a table: Della Porta, *De aeris transmutationibus* 11.

> is frozen and made denser in a more turbulent way, to hail. When it is relaxed, it makes fair weather.[52]

Della Porta supports his opinion with quotes from Pliny the Elder's (23–79) *Natural History (Historia naturalis)* and Senecas' (4 BC–65 AD) *Natural questions (Naturales quaestiones)*. Seneca's Stoic views on the active role of air as a life-bearing medium linking heaven and earth receive particular attention:

> On this subject, Seneca says: 'thus air is part of the world, and a necessary one. Air is what links heaven and earth [. . .] It gives to what is above all that it receives from the earth; it infuses heavenly force in earthly things' [. . .] Air is the cause making all animals live.[53]

As Della Porta pointed out, air gave humans and animals the breath of life, and actively carried sounds to the ear, smells to the nose and images to the eye.[54] In discussing air and its qualities, Della Porta rejected Aristotle's theory that it is warm and dry and, once again following the Stoics, assigned to it one single quality: coldness.[55] He concluded that 'air is the vehicle of all which is 'spirabilis' and is susceptible to heavenly influences', where the term "spirabilis" can mean "air-like" or "life-giving".[56]

The first phenomenon Della Porta discussed was the purest form of motion of air: the wind. He argued against Aristotle's theory of winds, according to which winds are not moving air but dry exhalations rising up from the earth, and instead agreed with Seneca that the origin of wind was to be sought in the air's power of self-propulsion, thanks to which it 'sometimes thickens, sometimes expands and purifies itself, or

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[52] 'De Metheoris tractaturo, bene erit ab aere ipso exordiri, is namque inter coelum et terram totus interiicitur, et materiam et fundamentum impressionum aerearum omnium praebet. Nempe fluctuans ventos facit, vehementius concitatus et attenuatus igem et tonitrua, contractus nubila, conspissatus pluviam, congelatus nivem, et turbulentius gelatus addensatusque grandinem, et distensus serenum facit' Della Porta, *De aeris transmutationibus* 14.

[53] 'Seneca ad haec: 'sic mundi pars est aer, et quidem necessaria. Hic est enim qui coelum terramque connectit [. . .]. Supra se dat quicqid accepit a terris; sursum vim syderum in terrena transfudit.' [. . .] Hic causa est ut cuncta animalia vivant.' Della Porta, *De aeris transmutationibus* 14–15.

[54] Della Porta, *De aeris transmutationibus* 15.

[55] Della Porta, *De aeris transmutationibus* 15–17.

[56] 'Est tandem aer spirabilium rerum vehiculum et caelestium influxuum suceptivus.' Della Porta, *De aeris transmutationibus* 17.

otherwise contracts, escapes and moves away'.[57] Finally, after offering a very broad spectrum of ancient opinions (and even a few medieval ones), Della Porta stated his own view on the subject by describing the inverted-glass experiment in the same way he had done in his Italian *Pneumatics*.[58]

The experiment was supposed to help explain the origin of winds, showing how the sun would heat up the air, which expanded both upwards and to the sides, pushing away the colder air nearer to it. As we saw in the previous section, however, this theory is nearly – but only nearly – correct. Della Porta referred to the same example offered by Benedetti: the wind which rises in summer when a cloud covers the sun.

> One might argue that, in summer days, when a cloud intercepts the light of the sun, in that shadow we immediately feel a breeze and an agitation of the air: the reason is that, because of the absence of heat, air reverts to its previous state and invites the air surrounding it which with its arrival refreshes us and, once this air has diffused or gone further, the breeze stops.[59]

There can be no doubt that Della Porta was influenced by Benedetti's reflections on air, fire and wind. However, for Benedetti, the origin of winds was only one among a large number of subjects in which he contradicted Aristotle's views. For Della Porta, instead, the subject becomes one of the pillars of a new theory of meteors. The explanation Della Porta gave was simple and plausible, but it was incorrect and offered little explanation with respect to observable winds. Nonetheless, the theory was advocated not only by Benedetti and Della Porta, but also by the Dutchman Cornelis Drebbel, to whom we shall now turn.

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[57] '[aer] modo spissat se modo expandi et purgat, alias contrahit, deducit ac differt.' Della Porta, *De aeris transmutationibus* 39.

[58] Della Porta, *De aeris transmutationibus* 43–45.

[59] 'Argumento esse poterit, quod aestivis diebus, cum opaca nubes solis lumen intercipit in ea umbra statim aura ac aeri agitatio praesentitur: ratio quia caloris absentia, aer ad pristinam sedem se convertendo ad se cirumfusum aerem invitat, qui novo adventu nos refrigerat, at diffusa vel praeterlapsa, quiescit aura.' Della Porta, *De aeris transmutationibus* 45.

Cornelis Drebbel: His Life and Work

Cornelis Drebbel of Alkmaar in the Netherlands (ca. 1572–1633) is a historical figure who exemplified the characteristics of the late Renaissance 'magus'.[60] In fact, the figure of Cornelis Drebbel may have inspired William Shakespeare (1564–1616) in creating Prospero, the king-magician of *The Tempest*, while Drebbel's machines were a model for some of those described by Francis Bacon in his *New Atlantis*.[61] In her monography *The body of the artisan: art and experience in the scientific revolution* (Chicago: 2004) Pamela H. Smith counts Drebbel among the Dutchmen representing the 'artisanal epistemology articulated by Paracelsus', according to which 'certainty was to be extracted from nature through bodily experience'.[62]

Drebbel holds a prominent place in discussions on the origin of the thermometer. This is hardly surprising, since he was considered the inventor of that instrument by numerous contemporary authors, as well as by later authorities such as Johann Heinrich Lambert (1728–1777).[63] In the seventeenth century, the non-sealed air-thermometer often went under the name of 'Drebbelian instrument'. However, even though Drebbel engaged in almost all kinds of experimental activities, he never made the slightest attempt at estimating degrees of heat and cold. Modern historians have established this beyond any doubt. What did he do, then, to have his name attached to the thermometer?

Drebbel's life was equally divided between court and workshop. As a young man, he became an apprentice to Hendrik Goltzius (1558–1617), an artist, engraver and alchemist who had set up shop in Haarlem. Drebbel not only worked with Goltzius as an engraver, eventually marrying his sister Sophia, but he also engaged both in engineering and in natural philosophy. By 1604 he had been granted patents for a water pump and a self-regulating, perpetually moving clock, had built a foun-

[60] On Drebbel's life and work, see: Harris L.E., "Cornelis Drebbel of Alkmaar" in: Harris L.E., *The two Netherlanders: Humphrey Bradley and Cornelius Drebbel* (Cambridge: 1961) 121–227; Jaeger F.M., *Cornelis Drebbel en zijne tijdgenooten* (Groningen: 1922); Tierie G., *Cornelis Drebbel (1572–1633)* (Amsterdam: 1932).

[61] Colie R.E., "Cornelis Drebbel and Salomon de Caus: two Jacobean models for Salomon's House", *Huntington Library Quarterly*, 18 (1954/55) 245–260; Sokol B.J., *Brave new world* 102–111 and pp. 118–124.

[62] Smith P.H., *The body of the artisan: art and experience in the scientific revolution* (Chicago: 2004) 162–164. The quote on artisan epistemology is from p. 155.

[63] Burckhardt F., *Erfindung* 6–7; Lambert J.H., *Pyrometrie oder vom Maaße des Feuers und der Wärme* (Berlin: 1779) 13–15; Wohlwill E., "Erfindung" 163–166.

tain in Middelburg, had become a close friend of the philologist and hermetist Gerrit Pieterzoon Schagen (1573–1616) and had published a *Short treatise on the nature of the elements and how they cause wind, rain, lightning and thunder and to what they are useful* (1604).[64] The book was written in Dutch and, while its original edition is very rare today, it was reprinted, possibly with modifications in 1621, 1688, 1701/02 and 1732. Within a few years it was translated into German (1608, repr. 1619, 1624, 1628, 1715, 1723), Latin (1621, repr. 1628, 1702) and French (1672).[65] No English version of Drebbel's treatise exists, and neither was the Latin version of the book printed in England: this is somehow surprising, since Drebbel spent a large part of his life in London.[66]

In the Netherlands, Drebbel conceived a "perpetuum mobile" which, as we shall see, was in more than one sense a weatherglass. In 1604, or shortly thereafter, he moved to London, where he succeeded in attracting the attention of King James I (reg. 1603–1625), to whom he presented his "perpetuum mobile", which was later put on display in Eltham palace. In 1609, the Dutchman was attached to the retinue of James's son Henry (1594–1612). Already in 1610 Drebbel left London for Prague, accepting an invitation from the emperor Rudolf II of Hapsburg (reg. 1576–1612).

For many years, Rudolf II had drawn to his court the most renowned – and sometimes the most infamous – artists, philosophers, astrologers/astronomers and natural magicians, including John Dee (1527–1608), Tycho Brahe (1546–1601) and Johannes Kepler (1571–1630).[67] Giovanni Battista Della Porta had been invited there, too, but had declined. In Prague, Drebbel engaged in alchemy and built a new version of his "perpetuum mobile". In 1611, though, Rudolf's brother, Matthew of Hapsburg (1557–1619), invaded Prague with the support of the

[64] *Een kort tractaet van de natuere der elementen, ende hoe sy veroorsaecken, den wind, reghen, blixem, donder, ende waromme dienstlich zijn*, title quoted from the edition printed in Haarlem in 1621. For a list of the editions and translations of this work, see: Hellmann G., "Entwicklungsgeschichte des meteorologischen Lehrbuches" 77–80, 84–86.

[65] The earliest edition of the treatise which was accessible to me was the German translation: Cornelius Drebbel, *Ein kurzer Tractat von der Natur der Elementen und wie sie den Wind, Regen, Blitz und Donner verursachen und war zu sie nutzen* (Leiden: 1608), from which all my references and quotes are taken.

[66] The English translation Hellmann lists with a question mark in Hellmann G., "Entwicklungsgeschichte des meteorologischen Lehrbuches" 77 was no translation, but an original work by Thomas Tymme.

[67] Grudin R., "Rudolf II of Prague and Cornelis Drebbel: Shakespearean archetypes?", *Huntington library quarterly* 54 (1991) 181–205, esp. 182–183.

Bohemian protestants and effectively deposed Rudolf, who died one year later. According to a later account, Drebbel was at first imprisoned, but later released and even invited to remain at the new court. He chose to travel back to England, instead. From this time forward, it becomes difficult to reconstruct Drebbel's movements, but it seems he spent most of his time in England, where he never again received royal patronage, in large part because Prince Henry had died in 1612. Nonetheless, Drebbel continued producing marvels, among them a submarine, as well as optical instruments and furnaces, which sold quite well. In his old age, he ran an alehouse in London, to which clients were attracted by his fame as a magician.

Drebbel's Treatise On the nature of the elements *(1604)*

Cornelis Drebbel's *Short treatise on the nature of the elements, and how they cause winds, rain, lightning, thunder and why they are useful* was first published in Dutch in 1604 and enjoyed a great popularity for the next 100 years, especially in Germany and the Netherlands.[68] Therefore, it can be assumed that the influence of Drebbel's ideas on European natural philosophy was not negligible, though this question has not yet been the subject of a systematic study.

Drebbel's treatise is profoundly different from Della Porta's. It is written in the vernacular and contains no quotes from the classic authors. Instead, it begins and ends with intensely religious remarks on how the study of nature attracts men to God, remarks that led the historian Gerrit Tierie to the conclusion that Drebbel was an anabaptist.[69] The contents of the book, however, are clearly influenced by alchemical practice and thought, containing, like Della Porta's meteors, the gunpowder theory of thunder and lightning.[70] Moreover, Drebbel, like Paracelsus,

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[68] A brief overview of the text, underscoring its Paracelsian character, can be found in Smith P.H., *Body* 162–163. The book is quoted as an original contribution to meteorology by Hellmann G., "Entwicklungsgeschichte des meteorologischen Lehrbuches" 49–50. Jankovic V., *Reading the skies* 180 recognizes that the text was influential, but inexplicably describes it as 'neo-scholastic'.

[69] Tierie G., *Drebbel* 18–19.

[70] Drebbel, *Kurzer Tractat* [21]. Since the pages of this edition are unnumbered, my references are made by counting from the title page, and are given in square brackets.

represented Creation as a process of chemical separation of the four elements out of an initial, undistinguished substance.[71] The Dutchman used the four Aristotelian elements, and not Paracelsus' "tria prima", but he established a clear hierarchy among them:

> Thus God separated His creation into four parts: fire, air, water and earth, and each has its power according to its subtlety. In this respect, fire is superior to all other elements and has the power to give them a clearness similar to its own. Fire gives life to all things and without it all things are dead, as we see everyday, especially in winter.[72]

Under the action of fire, air becomes like fire, water like air and earth like water.[73] Fire 'is the life of everything' and it is thanks to the fiery action of the sun on air and on the other elements that plants and animals live.[74] In Drebbel's explanation of weather, the interplay between fire, air and water was very important, as it is in modern meteorology. In the fourth chapter, Drebbel explained wind and rain by saying that the sun made air similar to fire and water to air, so that the two would rise and move around spreading humidity.[75] Eventually, when air-like water had risen up to where the air was cold, it turned again into water proper and fell down. At this point the air stood still. The way in which fire caused wind was demonstrated using the inverted-glass experiment, which was shown in the only illustration appearing in the treatise [Fig. 1]:

> [We see this] when we hang a glass retort with its mouth in a vase with water, and put a warm fire under the belly [of the retort], as this image instructs and explains. As soon as the air in the glass begins to become warm, we shall see that winds rise out of the mouth of the retort, and that the water fills with bubbles. And this will increase, as, with time, the air becomes warmer. But if we take away the retort from the fire, and the

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[71] Drebbel, *Kurzer Tractat* [7–9]. On alchemical Creation see: Debus A.G., "Aerial niter" 52.

[72] 'Also hat Gott sein Geschopf in vier theil geteilet: Feuer, Luft, Wasser und Erde und ein jegliches hatt seine Kraft, darnach sein Subtilitet ist darin das Feuer alle überrifft, und hat Macht ihnen eine Klarheit seiner Klarheit gleich zu machen, es gibt allen Dingen Leben, und sonder im seindt alle Dinge todt, wie wir alle Tag und vornehmlich im Winter sehen,' Drebbel, *Kurzer Tractat* [8].

[73] Drebbel, *Kurzer Tractat* [9, 12–13].

[74] Quote 'Also ist klar, das das Feuer das Leben ist von allem' is taken from Drebbel, *Kurzer Tractat* [11].

[75] Drebbel, *Kurzer Tractat* [14–15].

Fig. 1. The inverted-glass experiment as represented in: Cornelius Drebbel, *Short treatise on the nature of the elements (Kurzer Tractat von der Natur der Elemente)*, woodcut (1608).

> air begins to cool down, the air in the retort will again shrink, becoming coarse and thick, so that the glass will fill with water.[76]

Drebbel's and Della Porta's descriptions of the experiment are very similar. The Dutchman, too, emphasized the alchemical nature of the experience by using a retort. The accompanying picture represented the experiment as taking place under a tree and not in a laboratory, underscoring its natural character. Like Della Porta, Drebbel, too, explained how important it was to use a glass vessel, so that the activity of air can be seen.[77] However, quantification of the phenomenon could not have been further from Drebbel's thoughts. Another difference is

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[76] '[...] wan wir hangen eine ledige glaserne Retortam mit dem Mund in ein Fas mit Wasser und unter dem Bauch ein warm Feuer legen, wie diese figur ausweiset und mitbringt. So werden wir sehen, sobald der Lufft im Glas anfangt warm zu werden, das Winde steigen aus dem Mund der Retorten und das Wasser voller Blasen wird, und dis wirdt mehren, so lange der Lufft je lenger ie wermer wird, aber wenn du die Retorte vom Feuer nimbst, und der Luft wieder in der Retort ineinander gehen grob und dicke werden also das Glas wirt mit Wasser erfullet werden.' Drebbel, *Kurzer Tractat* 15–16.

[77] Drebbel, *Kurzer Tractat* 16.

the fact that Drebbel, while describing the air escaping from the vessel as "wind", did not claim that expanding air simply pushes cold air away. In fact, he raised doubts about such an explanation, and he did this in connection with the same phenomenon discussed by Benedetti and Della Porta.

> One might ask: how come then, that in summer we often feel the wind coming from the clouds and not from the place where water is made thinner and rises, a fact apparently contradicting what has been said until now?[78]

Drebbel's answer was that, in this case, wind was due to the fact that clouds cool down, sink and thus press on the air below them, causing it to escape on the sides.[79] Apparently, the Dutchman had noticed the discrepancy between his theory and observations, but did not know how to explain it in general.

Meteors, Alchemy and Pneumatics

Drebbel and Della Porta shared an interest not only in weather, but also in alchemical thought and pneumatic experiments. Although a direct influence of Drebbel on Della Porta cannot be ruled out, I would like to argue that the similarities between the two works can be traced back to a particular current of late Renaissance natural philosophy in which meteors, alchemy and pneumatics were closely aligned.

Even though Paracelsus had been the first one to use alchemical patterns to explain meteors, tradition had linked alchemy and meteorology long before him, as the two disciplines studying the characteristics and behaviour of the four elements. The fourth book of Aristotle's *Meteors* dealt with themes related to what later would be known as alchemy.[80] Moreover, alchemists were in a particularly good position to explain meteors, because knowledge of the thermodynamic properties of water, water vapour and air was, and still is, essential to make sense

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[78] 'Es möchte einer fragen, wie kommt es dan, das wir oftmals im Sommer den windt aus den Wolcken fühlen und nicht aus den Ort da das Wasser verdünnet, ode aufgezogen ist, welches dem vorigen zu wieder?' Drebbel C., *Kurzer Tractat* 19.

[79] Drebbel, *Kurzer Tractat* 19–20.

[80] Pepe L., "Introduzione", in: Aristotle, *Meteorologia*, ed. L. Pepe (Milano: 2003) III–XXVI, esp. XIX–XXVI.

of weather phenomena. Such knowledge could certainly be acquired by performing alchemical experiments.

Another way to learn about the properties of air and water, though, was the study and construction of pneumatic machines such as those described by Hero of Alexandria and built by Renaissance engineers. The philosophical significance of those devices had already been recognized by Cardano, who had included some of Hero's devices in his treatise *On subtility*.[81] By that time, clockwork mechanisms had long been taken up by philosophy to serve as models for conceiving cosmic order. Descartes even used them as a pattern to explain all bodily functions of living creatures. Less mechanically and mathematically-minded philosophers might instead have taken an interest in developing the philosophical potential of those technological novelties which, like alchemical experiments and pneumatic devices, could not (yet) be represented in geometrical-mathematical terms. Hence, alchemy and pneumatics might have been not so distantly related in the eyes of some early modern philosophers and both could contribute to a better understanding of (at least some) meteors.

However, the inverted-glass experiment did more than offer a plausible, anti-Aristotelian explanation of the origin of winds. In fact, as noted earlier, the explanatory power of the model was noticeably compromised by the false assumption that hot air would simply push away cold air. In my opinion, the fascination of the experiment was largely due to the fact that it offered a visual demonstration of the otherwise invisible activity of air under the influence of fire. This activity could be interpreted as the cause not only of wind, but of all atmospheric phenomena. In the next section, I will try to show how this feature, too, mirrored a general trend of late Renaissance natural philosophy.

Spirit, Air and Fire in Late Renaissance Europe

Both Drebbel and Della Porta saw meteors as both product and vehicle of a fiery, vital principle of heavenly origin, whose nature was neither fully corporeal nor fully incorporeal.

For Drebbel, the principle was the element fire, the most subtle part of Creation, which clarified air and the other elements, living in them

[81] Boas M., "Hero's Pneumatica" 41; Nenci E., "Introduzione" 22–27.

and giving them life. Della Porta's views were stated mostly by way of classical quotes and are not completely clear. However, he attributed to air the capability of carrying – or even actually transmuting into – a fiery spirit originating in heaven, which made life on earth possible.

This aspect of Drebbel and Della Porta's theory of meteors can be seen as part of a general tendency in Renaissance philosophy: explaining natural phenomena as resulting from the action of one (or more) subtle substance, neither fully corporeal nor fully incorporeal, variously referred to as "spiritus", "pneuma", "quintessence" or, sometimes, simply fire, air or wind.

I cannot offer here more than a rough sketch of this complex subject, whose various aspects have been dealt with in a large number of articles and monographies.[82] The origins of the various concepts of "spirit" as medium between corporeal and incorporeal elements of the cosmos can be traced back to Antiquity.[83] Stoicism, Neoplatonism and Aristotelian-Galenic medicine had each developed its own specific form of such a concept. These, in turn, had influenced the Fathers of the Church in their reflections on the Holy Spirit, until with Augustinus a definitely non-corporeal conception of the third divine person was established.[84] However, the term "spiritus" retained an ambiguous character in the middle ages and Renaissance and could be used to indicate both corporeal entities like air, breath or wind and incorporeal entities like the human soul's most discussed component, the intellectus ("mind").[85] As previously mentioned, treatises on pneumatics could be titled 'Spiritali'.

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[82] On the various concepts of "spirit" and their interaction and assimilation in the late Renaissance: Debus A.G., "Chemistry and the quest for a material spirit of life in the seventeenth century", in Fattori M. – Bianchi M. (eds.), *Spiritus. IV° colloquio internazionale* (Roma: 1984) 245–263; Garin E., "Relazione introduttiva", in Fattori M. – Bianchi M. (eds.), *Spiritus* 3–14; Klier G., *Die drei Geister des Menschen. Zur sogenannten Spirituslehre in der frühen Neuzeit* (Stuttgart: 2002); Putscher M., *Pneuma, spiritus, Geist. Vorstellungen vom Lebensantrieb in ihren geschichtlichen Wandlungen* (Wiesbaden: 1973); Walker D.P., *Spiritual and demonic magic from Ficino to Campanella* (Leiden: 1958); Walker D.P., "Medical 'spirits' and God and the soul", in: Fattori M. – Bianchi M. (eds.), *Spiritus* 223–244.

[83] On the concept of "pneuma" in Antiquity, see: Verbeke G., *L'évolution de la doctrine du pneuma du stoicisme á S. Augustin* (Paris: 1945, repr. 1987).

[84] Verbeke G., *Pneuma* 507–508.

[85] Armogathe J.-R., "Note brève sur le vocabulaire de l'âme au dix-septième siècle", in Fattori M. – Bianchi M. (eds.), *Spiritus. IV° colloquio internazionale* (Roma: 1984) 325–331; Bautier A.-M., "'Spiritus' dans les textes antérieurs à 1200. Itinéraire lexicographique médiolatine: du souffle vital à l'au delà maléfique", in Fattori M. – Bianchi M., *Spiritus.* 113–132; Hamesse J., "Spiritus chez les auteurs philosophiques des 12ᵉ et 13ᵉ siècle", in Fattori M. – Bianchi M., *Spiritus* 157–190.

All these traditions were either still alive or revived in the Renaissance, when the philosophical potential of various ideas of "spirit" was fully exploited. Particularly important was Stoic cosmology, as expounded by Cicero and Seneca.[86] For the Stoics, "spiritus" or "pneuma" was a mixture of air and fire which brought life from the celestial regions down to the earth and, at the same time, brought nourishment back from earth for the celestial beings. In Stoicism there was no clear-cut dichotomy between matter and soul, and the whole world was considered animated. Stoic pneuma had both corporeal and incorporeal features and could be seen both as a breath of life and as a divine, immanent intelligence. Stoic philosophy reached Renaissance thinkers both directly, through ancient sources, and indirectly, by way of its influence on Neoplatonism and medicine. Stoic concepts were often found in Renaissance texts on natural philosophy and alchemy and played a prominent role in challenging Aristotelian worldviews. As far as the study of meteors is concerned, Stoicism was particularly relevant, since it had a long tradition of paying attention to such phenomena and explaining them; winds and tides, for example, were said to result from the activity of the all-pervading pneuma. One Stoic work largely devoted to meteors was, of course, Seneca's 'Natural questions', so frequently quoted by Della Porta.[87]

Another source for ideas on "spirit" in the Renaissance was Neoplatonic philosophy, which was rediscovered and reshaped in the fifteenth century. In Marsilio Ficino's (1433–1499) *Three books on life* (*De vita libri tres*, 1489), the 'spirit of the world' ('spiritus mundi') was the mediator between matter and the fully immaterial 'soul of the world' ('anima mundi').[88]

> [Spirit] is a very subtle body; as it were not body and almost soul. Or again, as it were not soul and almost body. Its power contains very little earthy nature, but more watery, still more aerial and the maximum of

[86] On ancient Stoic doctrines of pneuma: Verbeke G., *Pneuma* 11–174, summary on pp. 172–174. On Stoic influence on Renaissance natural philosophy: Barker P., "Stoic contributions"; Joly B., "Présence des concepts de la physique stoicienne dans les textes alchimiques du XVII[e] siècle", in Margolin J.C. – Matton S. (eds.), *Alchimie et philosophie à la Renaissance* (Paris: 1993) 341–354.

[87] On pneuma in Seneca's work, see: Verbeke G., *Pneuma* 143–157.

[88] On Ficino's "spiritus": Walker D.P., *Magic* 12–13, 22–23; Garin E., "Relazione introduttiva" 6–8.

> fiery and starry nature [...] It vivifies everything and everywhere and is the immediate cause of all generation and motion.[89]

Similar conceptions of spirit and spirits were part of Renaissance natural magic, where they worked as mediators between macrocosmos and microcosmos.[90] The spirit of the world interacted with an analogous spirit present in human beings, the astral body, which connected body and soul. The astral body was a Neoplatonic concept which some Renaissance authors assimilated to yet another traditional concept of "spirit", that of Aristotelian-Galenic medical spirits.[91] Medical spirits were the media through which the soul controlled the body. Originally, they were considered as corporeal: a fine, hot vapour which was a main component of live breath and of arterial blood. In some Renaissance authors, though, they could also be thought of in Neoplatonic terms, as a middle substance between body and soul, conveying both vital heat and the influence of the stars. As many historical studies have shown, these various conceptions of "spirit" circulating in the Renaissance period, though in principle radically different from each other, could interact or be assimilated to each other, eventually raising again questions about the corporeal nature of the Holy Ghost.[92]

While conceptions of spirits were developed in all branches of Renaissance philosophy, they played a particularly important role in alchemical thought.[93] Paracelsus and his followers were undoubtedly influenced by ancient tradition, but the development of alchemical practice had added new material which stimulated interest in and reflection on the role of "spirit" in nature. An alchemical pattern to think about not-quite-corporeal substances had been provided by the discovery of how to distil the "spirit of wine", which Paracelsus indicated with the name

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[89] '[Spiritus] vero est corpus tenuissimus, quasi non corpus, et iam anima. Item quasi non anima, et quasi iam corpus. In eius virtute minimum est naturae terrenae, plus autem aquae, plus ite aeriae, rursus ignae stellaris quamplurimum [...] Ipse vero ubique viget in omnibus generationis omnis proximus author atque motus.' Both the Latin text and the English translation are quoted from Walker D.P., *Magic* 13.

[90] On Renaissance spiritual magic: Walker D.P., *Magic*.

[91] Klier G., *Drei Geister* esp. 21–62; Walker D.P., "The astral body in Renaissance medicine", *Journal of the Warburg and Courtauld institutes* 21 (1958), 119–133; Walker D.P., "Medical 'spirits'".

[92] Walker D.P., "Medical 'spirits'".

[93] Figala K., "Quintessenz", in Priesner C. – Figala K. (eds.), *Alchemie. Lexikon einer hermetischen Wissenschaft* (Munich: 1998) 300–302; Hild H., "Geist", in Priesner C. – Figala K., *Alchemie* 147–148; Joly B., "Pneuma", in Priesner C. – Figala K., *Alchemie* 284–285.

of ‘alcohol vini’, i.e. ‘the most subtle part of wine’.[94] Like alcohol in wine, “spirits” or “quintessences” were allegedly present in all kinds of bodies as pervading, subtle substances that could not be isolated mechanically, but only alchemically, through distillation. Ideally, repeating the process of distillation an appropriate number of times on the right ingredients, one might eventually obtain “the” quintessence, i.e. the philosopher’s stone.

A further alchemical pattern for thinking vital spirit was gunpowder, with its key component saltpeter (potassium nitrate). In the Paracelsian corpus, a fiery spirit variously indicated as “salpeter”, “aerial niter” or “nitrous salt”, analogous to the corresponding earthly substances, was assumed to be present in the air.[95] It was considered to be the cause of thunder and lightning, a necessary “food” for living creatures and the origin of some fiery diseases. This theory was further developed by Joseph Du Chesne (1544–1609), who described the vital niter of the air as an ingredient of salpeter, which was seen as a life-giving substance produced by a process of cosmic distillation. We may recognize the similarity to the theory of meteors proposed by Drebbel. In the seventeenth century, the idea of a life-giving “aerial niter” or “flamma vitalis” present in the air and responsible for respiration, combustion, thunder and lightning as well as, according to some authors, for snow and earthquakes, became quite common.[96]

Though they were particularly important for alchemists, “spirits” in the ambiguous sense discussed above played a prominent role also, for example, in the works of Francis Bacon.[97] According to the reconstruction by the historian Graham Rees, in his speculative philosophy Bacon made frequent use of the concept of “spiritus vitalis”, a mixture of fire and air which conferred living beings most of their faculties.[98]

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[94] Quoted from: Stillman J.M., *The story of alchemy and early chemistry* (New York: 1923 repr. 1960) 192. In general on this subject: Figala K., “Quintessenz”; Taylor F.S., “The idea of the quintessence”, in ed. E.A. Underwood, *Science, medicine and history. Essays in the evolution of scientific thought and practice written in honour of C. Singer*, vol. 1 (London: 1953) 247–265.

[95] Debus A.G., “Aerial niter”, especially p. 48; Guerlac H., “The poet’s nitre”, *Isis*, 45 (1954) 243–255.

[96] Debus A.G., “Aerial niter” 59–61. In particular, on aerial niter and meteors: Guerlac H., “The poet’s nitre” 250–254.

[97] Fattori M., “‘Spiritus’ dans l’‘Historia vitae et mortis’ de Francis Bacon”, in Fattori M. – Bianchi M. (eds.), *Spiritus* 283–323, Rees G., “Francis Bacon and ‘spiritus vitalis’”, in Fattori M. – Bianchi M., *Spiritus* 265–281; Walker D.P., “Francis Bacon and ‘spiritus’”, in ed. A.G. Debus, *Science, medicine and society in the Renaissance*, vol. 2 (London: 1972) 121–130.

[98] Rees G., “Francis Bacon” 275–276.

This brief overview on the role of spirit and spirits in Renaissance natural philosophy has hopefully shown how the inverted-glass experiment, when presented as a visual demonstration of activity of fiery air, could not fail to attract attention. As already noted, air, and especially wind, were traditional candidates for a corporeal manifestation of spirit. Moreover, in the Holy Scriptures, particularly in the Old Testament, winds played a very important role both as weather phenomena and as manifestations of the divine.[99] In the Bible, a large number of quotations could be found to support the double interpretation of the term "spiritus" which was common in the middle ages. Winds also featured prominently in a pivotal text for alchemical thought: *The Emerald Table*, which began with the words:

> True it is, without falsehood, certain and most true. That which is above is like to that which is below, and that which is below is like to that which is above, to accomplish the miracles of one thing.
> And as all things were by contemplation of one, so all things arose from this one thing by a single act of adaptation.
> The father thereof is the Sun, the mother the Moon.
> The wind carried it in its womb, the earth is the nurse thereof.[100]

It is worth noting that the *History of the winds* was the first part of Francis Bacon's *Natural history*.[101] In this work, he expounded a theory on the nature and origin of winds which was a mixture between traditional Aristotelian doctrine and the ideas of Benedetti, Drebbel and Della Porta.[102]

Therefore, the special significance acquired by the inverted-glass experiment in Drebbel's and Della Porta's treatises was neither a coincidence nor purely the result of direct influence. It was rather a quite successful attempt at applying new and rapidly developing forms of natural philosophical thought to a new field of great public interest, i.e. the study of meteors. These new trends reflected not only more or

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[99] Sevrin J.-M., "'Spiritus' dans les versions latines de la bible", in Fattori M. – Bianchi M., *Spiritus* 77–91.

[100] The quote is taken from: Linden S.J. (ed.), *The alchemy reader. From Hermes Trimegistos to Isaac Newton* (Cambridge: 2003) 28, which reproduces a transaltion by Steele R. – Waley Singer D., *Proceedings of the Royal Society of Medicine*, 21 (1928) 486. On the special position of winds in Renaissance alchemy, see also: Böhme G. – Böhme H., *Feuer Wasser Erde Luft. Eine Kulturgeschichte der Elemente* (Munich: 1996) 235–240.

[101] Ellis R.L., "Preface to the 'Historia ventorum'".

[102] Bacon, "Historia ventorum", in Bacon, *Works*, vol. 2, 13–78, here especially 46–48.

less abstract, esoteric traditions, but also new developments in medical, alchemical and pneumatic-hydraulic experience. The new technical artefacts were used to demonstrate the analogical unity of microcosmos and macrocosmos to the senses.

This style of theorizing was anything but homogeneous and eventually came to be associated not only with philosophical, but also with political and religious protest under the label of "Rosicrucianism".[103] On the natural philosophical level, it found two main opponents: on the one hand, the Catholic church and its official Aristotelian worldview, usually represented by the Jesuits; on the other, the representatives of a mathematical-mechanical, often corpuscularist worldview, like Galileo and, later, René Descartes. Though these two groups were at odds on many questions, notably Copernicanism, both argued for a clear-cut distinction between corporeal and incorporeal and both favoured mechanical, i.e. clockwork-type devices, as models for natural philosophical thought.

The meteorological opinions of each group found expression in two works already mentioned: Libert Froidmont's Aristotelian *Six books on meteorology* and Descartes's corpuscolarist *Meteors*. Right at the beginning of the section dealing with winds, Froidmont attacked ancient and modern theories defining wind as moving air, particularly the 'Stoic dreams' of air as 'animal' capable of moving out of its own will.[104] Descartes, instead, explained winds mechanically, as the result of the pressure of vapours of various kind and, of course he, too, denied air any active role.[105]

In the next section, we shall see how Cornelis Drebbel contributed to speculations about the moving power of air, not only with his writings, but also with his most famous invention: a perpetual motion machine.

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[103] Gilly C., "Die Rosenkreuzer als europäisches Phänomen im 17. Jahrhundert und die verschlungenen Pfade der Forschung", in: Gilly C. – F. Niewöhner (eds.), *Rosenkreuz als europäisches Phänomen im 17. Jahrhundert* (Amsterdam: 2002) 19–56.

[104] 'aer animal non est, ut somniant Stoici.' Libert Froidmont, *Meteorologicorum libri sex* (London: 1656) 178.

[105] Descartes, *Météores* 94–99.

Drebbel's "perpetuum mobile" and its Trapped Spirit

Thanks to a thorough search in printed and manuscript sources, historians have collected a large amount of evidence on the structure and function of Drebbel's "perpetuum mobile".[106] In fact, it would be more correct to speak of "perpetua mobilia", since the Dutchman built more than one version of the device. As far as we can tell, though, they were all based on the expansion and contraction of air which caused water to move right and left inside a curved glass tube. The more complex versions of the device also featured a self-regulating clockwork showing the calendar date and the position of the stars, although it is impossible for us to say how (and whether) these parts actually worked. In this paper, the main interest rests on the movement of the water, which was the most prominent feature of the machine in the eyes of its beholders. There can be no certainty on how the device was really built, since none are extant, but, according to reconstructions by contemporaries and historians, it was composed of a hollow metal sphere and of a circular glass tube larger than the sphere, which was fixed around it, passing above and below it. [Fig. 2].

The glass tube was divided in two by a partition at its uppermost point. To the left side of the partition, the inside of the glass tube was connected to the inside of the sphere. On the right side, instead, the tube was perforated and exposed to the atmosphere. The glass tube was half-filled with water, so that the air on the left side was trapped between the water surface, the walls of the tube and those of the sphere. On the right side, the air was free to enter and exit the glass tube. When the air trapped in the spherical reservoire heated or cooled, the water level sank or rose on the left side of the tube, and consequently rose or sank on the right side. The same movement took place also when atmospheric pressure increased or decreased.

[106] The most recent collection and discussion of the sources relevant to Drebbel's device and its reception in Europe is Drake-Brockman J., "The 'perpetuum mobile' of Cornelis Drebbel", in Hackmann W.D. – Turner A.J. (eds.), *Learning, language and invention. Essays presented to Francis Maddison* (Ashgate: 1994) 124–147. However, I will challenge her interpretation of the reception in terms of a doomed old philosophy of Aristotelian and/or Rosicrucian inspiration clashing with new natural philosophy represented by Galileo's circle (Drake-Brockman J., "perpetuum mobile" 146–147). Further discussions of Drebbel's device are: Michel H., "Le mouvement perpetuel de Drebbel", *Physis* 13 (1971) 289–294; Tierie G., *Drebbel* 37–42, Harris L.E., "Drebbel" 149–159.

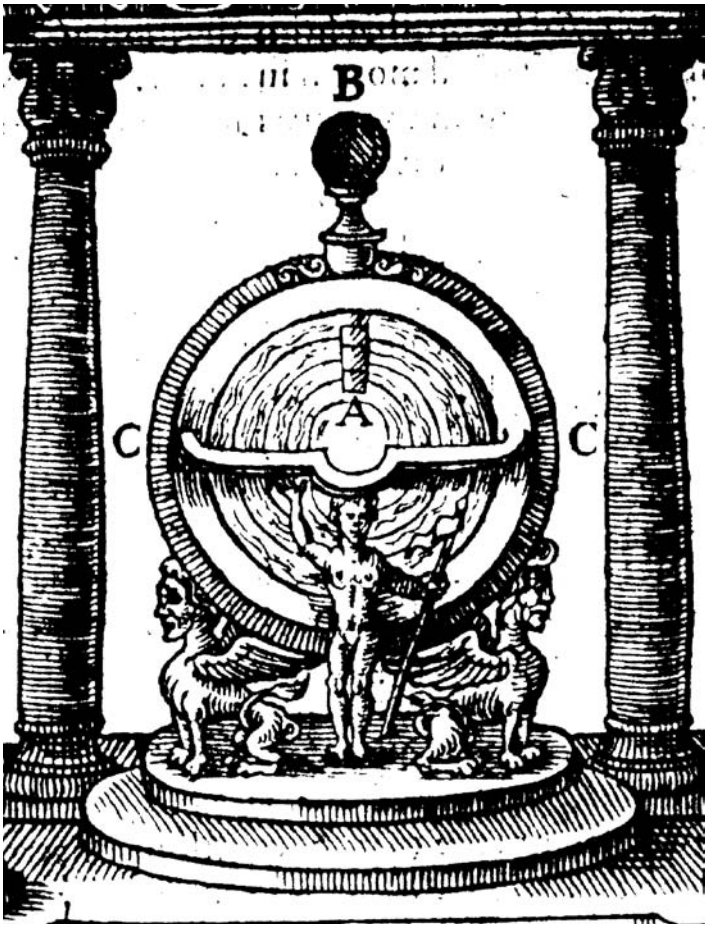

Fig. 2. Drebbel's perpetual motion device as represented in: Tymme T., *A dialogue philosophicall: wherein natures secret closet is opened and the cause of all motion in Nature shewed out of matter and forme. Together with the wittie invention of an artificial perpetual motion (by Corn. Drebbel)* (1612), woodcut (detail).

If this reconstruction is accurate, Drebbel's device was nothing but a fanciful form of the set-up for the inverted-glass experiment.

The earliest evidence of Drebbel's perpetuum mobile is a letter written in London, most likely in 1604.[107] The writer, John Speed, who saw the device before it was presented to King James I, was fascinated by its motion and even made a sketch of it. In the letter he stated, among other things:

> Round about the east and west parts doth a ring or hollow trunke of christall stand and that without moving and the same filled to his halfe with fayre water, which without any instrument that can be perceived doth ebb and flow with the Seas in every part of the world, my self stayed so longe that I sawe it ascend up the trunk a good height and left the lower compasse of the ringe empty.[108]

In 1607, Drebbel presented his perpetual motion device to James I, and we have an eyewitness account of that moment in the travel diary of Heinrich Hiesserle von Chodaw, a gentleman from Bohemia.[109] The description shows Drebbel's theatrical skills in the way he half-explained the device to the king. Particularly interesting for us is the following remark:

> The King then asked again from what the perpetual motion derived its power, to which he answered shortly, saying that it was the Air, the principal element, which made all things move.[110]

This explanation is correct from the modern scientific viewpoint, but also fits in with the spiritual trend in Renaissance natural philosophy discussed in the previous section. An early evidence of the context in which Drebbel intentionally placed his "perpetuum mobile" is contained in a work published in 1607 by Drebbel's friend Gerrit Schagen. The book contained: (1) four short extracts praising Archimedes' sphere, three taken from ancient authors and one from a contemporary, (2) a letter written by Drebbel to James I, to offer him his "perpetuum mobile", later translated into Latin and often published together with

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[107] Drake-Brockman J., "perpetuum mobile" 125–127. On p. 125, the sketch is reproduced.

[108] I quote after Drake-Brockman J., "perpetuum mobile" 125. The text is taken from Bodleian Library MS Ashmole 1813, f. 374.

[109] Drake-Brockman J., "perpetuum mobile" 128–129.

[110] I quote from Drake-Brockman J., "perpetuum mobile" 128. The text is translated from the original German contained in Hiesserle von Chodow H., Raiss Buch und Leben, Prague Nat. Mus. vi A 12, ff. 48v–50r.

other works by Drebbel, and (3) Schaden's translation from Italian into Dutch of the *Pymander*, a Hermetic treatise from late antiquity.[111]

The parallel between Archimedes's sphere and Drebbel's machine was later taken up by many authors.[112] Archimedes' device was a kind of armillary sphere i.e. a mechanism geometrically representing the cosmic spheres. Although it was probably water-driven, only the motion of its mechanical parts was philosophically relevant. Thus, Drebbel's pneumatic perpetual motion was assimilated to mechanical clocks, which, from the philosophical point of view, were arguably the most relevant technological development of the late medieval and early modern period. Drebbel's "perpetuum mobile", however, not only showed celestial motion, but also made its moving force visible, as the Dutchman wrote to James I:

> Knowing ebb and flow, I build an instrument which continually ebbs and flows each 24 hours, perpetually showing the months and their days, the phases of the moon and the hours, and the tides. [...] This is the offshoot or a branch of the tree of perpetual motion, rooted in the real knowledge of the elements.[113]

Here, Drebbel linked the motion of the water with that of the tides. This explanation will have certainly appeared plausible to many spectators, since moving water was the most prominent feature of the "perpetuum mobile". However, it was wrong and Drebbel knew it, having himself offered the right one both in his treatise and in his explanation to James I. Possibly, the Dutchman was acting like a natural magician should, providing a philosophical bait for those who wanted to learn more. If they read his treatise, experimented themselves or repeatedly

[111] 'Wonder-vondt van de eeuwige beweginghe, die den Alckmaersche Philosooph Cornlis Drebbel door een eeuwigh bewegende gheest in een Cloot besloten te weghe gebrocht heeft welchers toeeygeningh (in 't vereerendes selvigen aen den grootmachtigen Coningh Jacob van groot Brittangen) allhier naecktelijck vertoont wordt.' A facsimile reproduction of the work can be found in: *De Alkmaarder Cornelis Drebbel. Uitvinder, hermetist, alchemist* (Harlem: 2005).

[112] On the parallel between Drebbel's machine and Archimedes' sphere: Drake-Brockman J., "perpetuum mobile" 143.

[113] 'At cognitione fluxus et refluxus eficio instrumentum semper fluens et refluens singulis 24 horibus, ostendens menses eorumque dies, cursum lunae et horas, fluxus et refluxus in perpetuum. [...] Illud est propago vel surculus arboris perpetui mobilis, insitus verae cognitionis elementorum.' I quote from the Latin translation printed as an appendix to: Cornelius Drebbel, *Tractatus duo: prior de natura elementorum, posterior de quinta essentia* (Hamburg: 1621) [11]. Since the pages of this work are unnumbered, My reference is made by counting from the title page of Drebbel' letter.

questioned, as the king had done, they would learn the true cause of the motion, i.e. the activity of air.

Popularity of and Reactions to Drebbel's "perpetuum mobile"

Thanks to the theatrical skills of its inventor, Drebbel's perpetual motion machine attained fame throughout Europe in the following decades. After it was put on show in Eltham Palace, it became so well know, that it was used in jokes by Ben Jonson (1573–1637) and other satirical writers.[114] According to some literary historians, the "perpetuum mobile" might even have provided inspiration for Shakespeare's description of Ariel as an imprisoned spirit.[115] As contemporary paintings show, small replicas of it were being sold to wealthy clients for their cabinets of curiosities.[116]

Further evidence of how Drebbel's machine, or devices similar to it, had become a commercial success is found in a remark made by the physician Henri de Heer (1570–1636) in a polemic writing addressed to Jan Baptista van Helmont (1577–1644). De Heer argued that water can transform into air, offering the following evidence:

> To demonstrate the idea of perpetual motion, and at the same time show which part of the house is warmer, which colder and which temperate, a smart mathematician has build a glass in which he, with great understanding, completely enclosed air together with some red water [...]. And what happened? In my house as well as in many other places, the precious water disappeared and was therefore transformed into air, since there was no other way out. The whole of Liège, His Highness the Prince, the whole court and I do not know how many visitors of Spa have held these glasses in their hands, have looked in and have felt sorry for the transformation of the water into air, because in that moment the mathematical marvel had ceased to be.[117]

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[114] Sokol B.J., *Brave new world* 106–111.

[115] Grudin R., "Rudolf II" 192–193. The connection between the Tempest and weatherglasses/thermometers is a central theme of Sokol B.J., *Brave new world* esp. 102–124.

[116] Michel H., "Mouvement perpetuel" 290–291.

[117] It was unfortunately impossible for me to access the original, Latin version of this text, which is taken from: Heinrich van Heer, *Deplementum supplementi de Spadanis fontibus* (1624) so I translate here the German translation found in Wohlwill E., "Neue Beiträge" 145–146: 'Ein scharfsinniger Mathematiker, um uns den Begriff einer immerwährender Bewegung anschaulich zu machen und zugleich erkennen zu lassen, welcher Teil des Hauses wärmer, welche kälter, welcher mäßig kühl sei, ein

De Heer did not give a description of the glass, but van Helmont did so in his reply. From his description it appears that what the 'smart mathematician' was selling as a "perpetuum mobile" was nothing other than a simplified version of Drebbel's device. It had the form of a J-shaped glass tube, open at its lower end and partially filled with water. Could the seller have been Drebbel himself or was it only an imitator? Maybe one of his sons-in-law, whom we know took part in his commercial enterprises? Whatever the answer, this passage shows how pneumatic perpetual motion was becoming a commercial success in Northern Europe. There is also evidence that in 1620s such devices also appeared in Italy: from a letter of Cesare Marsili (1592–1633) to Galileo we learn that in Bologna, in the year 1626:

> A certain engineer passed by, who claimed that, using some salty or marine water, he showed in certain glass flasks the motion of ebb and flow of the sea caused by celestial and intrinsic virtue.[118]

In his answer, Galileo explained that the motion was in all probability due to the thermal expansion and contraction of air, on which he had experimented twenty years before, and had nothing to do with the tides. Marsili replied:

> What I had written you about the flasks showing ebb and flow of the sea has turned out to have no substance, but they had a different use, which I however have not been able to see up to now, even though I hope I shall be able to do so in a short while.[119]

Unfortunately, from Galileo's correspondence we learn nothing more about the real use of the flasks, and we may only speculate whether it

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Glas hergestellt, in dem er sinnreich ein tiefrotes Wasser [...] mit Luft vollkommen eingeschlossen hatte. Aber was geschah? Sowohl in meinem Haus wie an verschiedenen anderen Stellen ist das kostbare Wasser verschwunden und in Luft übergangen, denn einen anderen Ausgang gab es nicht. Ganz Lüttich, der durchlauchtigste Prinz, der ganze Hof, unzählige Besucher von Spaa haben diese Gläser in Händen gehalten und gesehen, haben die Verwandlung des Wassers in Luft schmerzlich bedauert, denn im selben Augenblick war es aus mit dem Wunder der Mathematik.' The following discussion is based on: Wohlwill E., "Neue Beiträge" 147–150.

[118] 'Un certo ingegniero, qual pretende con certa acqua salsa o marina mostrare in certe ampolle i moti dei flussi et reflussi de' mari, cagionati per celeste et intrinseca virtù.' Galileo Galilei, *Opere*, vol. 13, 316. The letters I discuss here are edited in: Galilei, *Opere*, vol. 13, 316–317, 319–320, 326, 327–328.

[119] 'Quanto le havevo scrito di quel'ampole, che mostravano il flusso e riflusso del mare, era riuscito una vanità, ma havevano un uso differente, il quale però sin ad hora non ho potuto vedere, anchorchè fra poco lo speri.' Galilei, *Opere*, vol. 13, 326.

had to do with perpetual motion, thermoscopy or weather forecasting. In any case, there can be no doubt that the device shown was some form of the inverted-glass experiment which was starting to circulate in Italy, too. We shall come back to the J-shaped tube and its special relationship to the Netherlands in a later section: let us now return to Drebbel.

The fame of Drebbel's machine was responsible for the fact that the unsealed air-thermometer became known as a 'Drebbelian instrument', a term used already around 1625 in the Netherlands, to indicated both Drebbel's "perpetuum mobile" and the instrument to measure the temperature of the air.[120] What is particularly relevant to our inquiry, though, is that the device brought the apparently active character of air to the attention of a broader public. After the initial marvel, many philosophical discussions arose on the subject, as ample evidence shows.[121] The perpetual motion was seen by some as demonstrating a primal moving force of nature, while others interpreted it as a trivial application of a well-known, philosophically not particularly relevant phenomenon. Among those who shared the first opinion were many 'chemical philosophers'. One of them was Thomas Tymme (fl. 1566–1612) who, having previously translated into English the works of the Paracelsian Joseph Du Chesne, in 1612 published a book titled: *A dialogue philosophicall: Wherin natures secret closet is opened and the cause of all motion in Nature shewed out of manner and forme. Together with the wittie invention of an artificiall perpetual motion (by Corn. Drebbel)*.[122] Drebbel's 'artificial perpetual motion' was described, discussed and represented in an engraving. Like Drebbel and Schagen, Tymme, too, regarded the device as a visual demonstration of the principle of all motions.

A completely different reaction was that of Daniello Antonini (1588–1616), who belonged to the circle of Galileo.[123] In the year 1612, Antonini wrote to Galileo from Brussel that he had heard of James

[120] 'Drebbeliaensche instrument' (Beeckman I., *Journal*, ed. C. De Waard, vol. 2 (La Haye: 1942) 361, 361 n. 3.

[121] Drake-Brockman J., "perpetuum mobile" 141–145; Harris L.E., "Drebbel" 156–158.

[122] On Thomas Tymme see: Debus A.G., *The English Paracelsians* (New York: 1966) 87–97. The role of Drebbel's pertpetual motion in Tymme's book is discussed in detail in Harris L.E., "Drebbel" 152–155. Inexplicably, in Jankovic V., *Reading the skies* 180–181 Tymme's treatise is erroneously attributed to Drebbel.

[123] On Antonini's short life, see: Galileo, *Opere*, vol. 20 (1968) 372–373. The letters which I summarize here are edited in Galileo, *Opere*, vol. 11 (1968) 269–270 and 275–275.

I's perpetual motion machine 'in which water moves up and down in a glass tube, like (as they say) the ebb and flow of the sea.'[124] He had also seen a drawing of the device and had thought about it, concluding that the movement must be caused by the heating and cooling of the air in the tube. His conclusion was based on the 'speculations on those experiments with the large glass' which Galileo knew about, obviously some form of the inverted-glass experiment.[125] This is the earliest evidence explicitly connecting the inverted-glass experiment with Drebbel's device. Antonini did not limit himself to speculations: he went immediately from thought to action and built a model of the machine, which he later presented to Albert of Austria. Proudly he described to Galileo how he had explained to an incredulous audience that he had discovered the secret of the device.

Jennifer Drake-Brockman interprets this episode in the context of a clash between an old-fashioned magical-philosophical stance and the emerging scientific worldview.[126] Yet, I would argue, this interpretation is too reductive, erroneously contrasting Antonini's and Drebbel's attitudes as respectively scientific and non-scientific. Antonini sought the cause of motion in mechanical terms, explaining the movement of water as the result of the force of expansion and contraction of air under the influence of heat, by then a well-known phenomenon. Having reached this conclusion, he did not go further, asking, for example, why air would acquire moving force under the action of heat. This is today a scientifically very relevant question, answered in terms of energy. In the early seventeenth century, those who marvelled at the perpetual motion and asked the same question, often answered it in terms of fiery spirits. Thus, the same technological artefact could inspire different reflections according to the natural philosophical views of the beholder. However, it is very important to note a characteristic which Drebbel and Antonini shared: they both were ready to let technological artefacts influence their philosophical reflections.

[124] 'nel quale entro un canale di vetro si move certa acqua, hor alzandosi hor abbassandosi, a guisa (dicevasi) del flusso e del reflusso del mare.' (Galilei, *Opere*, vol. 11, 269).

[125] 'speculazioni di quelle esperienze del bellicone' (Galilei, *Opere*, vol. 11, 270).

[126] Drake-Brockmann claims that 'the "perpetuum mobile" was the product of a thoroughgoing Aristotelian cosmology' (Drake-Brockmann J., "perpetuum mobile" 146) and at the same time describes Drebbel's claims to knowledge of perpetual motion as part of a 'doomed Rosicrucian obsession' (Drake-Brockmann J., "perpetuum mobile" 147).

Santorio Santorio and Aristotelian Degrees of Heat and Cold

Santorio Santorio (1561–1636) was born in Capodistria, at the time part of the Venetian Republic, studied medicine in Padua and worked as a physician first in Croatia and later in Venice.[127] Thanks to his skills as a physician and to the success of his first book on Galenic medicine, in 1611 he became a professor of theoretical medicine in Padua, where he lectured, practised and published the results of his medical experiments, mostly in the form of commentaries to classical medical texts. In 1624 he retired from the university, but continued practising and publishing.

Despite being based on Aristotelian-Galenic theories, Santorio's work was deeply original. He attributed great importance to experiment and especially to operational quantification. To this end, he devised a number of instruments for measuring, among other things, the rapidity of the pulse and humidity as well as weight loss and gain due to ingestion, excretion and perspiration.[128] In 1614, he wrote a treatise *On static medicine (De statica medicina)* which enjoyed immediate success and remained highly appreciated for more than a century.

Among the instruments Santorio used, there was one whose function was to determine degrees of heat and cold. It was identical with the set-up for the inverted-glass experiment. Santorio mentioned it briefly for the first time in his commentary to Galen (1612) and described it in greater detail later in his commentary to Avicenna's canon (1625).[129] In the latter work, the device was shown in a picture and described in these words:

> The image is a glass vase thanks to which we can very easily, in every hour determine the cold or hot temperature, and we can learn every hour in a most perfect way how much the temperature deviates from the natural state measured before. This vase is put by Hero to another use. We have adapted it so that it serves to discern the cold and hot temperature of

[127] My overview on Santorio's life and work is based on: Grmek M.D., "Santorio Santorio", *Dictionary of scientific biography* 11 (1975) 101–104. On Santorio's device to measure degrees of heat and cold see: Taylor F.S., "Origin" 129–132 and 135–140. Caverni R., *Storia*, vol. 1, 265–270.

[128] For a description of all of Santorio's instruments and a collection of the corresponding original quotes, see: Grmek M.D., *Santorio Santorio i njegovi aparati i instrumenti* (Zagreb: 1952) 64–70.

[129] Santorio S., *Commentaria in artem medicinalem Galeni* (1612) c. 62; Santorio S., *Commentaria in primam fen primi libri Canonis Avicennae* (1625).

> the air, and of all parts of the body, and to learn the degree of hotness of those who have fever.[130]

Later on, Santorio described various versions of his device for measuring the 'hot or cold temperature' of a patient.[131] He also used the instrument to determine the temperature of the air and to test whether the moon really emitted cold rays, as some astrologists claimed.[132] He was glad to show that, according to his measurements, the moon emitted warm rays just like the sun: the Paduan professor was an enemy of astrology and even subscribed to Copernican theory.

However, the degrees of heat and cold that Santorio was measuring were no novelty, but instead had a very long tradition in Aristotelian-Galenic medicine.[133] Quantification and mathematisation had played a role in that tradition since the writings of Galen (ca. 129–200) and had been greatly developed first by Arabic-Islamic and later by Latin-Christian physicians. This tradition was very important for early modern thermometry, if only because, as we just saw, it is the source of the terms 'temperature' and 'degree of heat and cold'.

In his works, Galen had used as a basis the Aristotelian doctrine of the four qualities (hot, cold, humid and dry) forming two pairs of opposites whose balance in a body determined its characteristics. Thus, in the form of each body, the qualities of hotness and coldness were always both present, and partly or completely balanced each other, determining the "temperature" (or "temperament") of the body as more or less hot or cold. According to Galen and his followers, the "temperature" of hotness and coldness in a body could be classified on a numerical scale of four degrees of coldness to four of hotness. Aristotelian-Galenic hotness and coldness did not refer only to tactile sensations, but also, for example, to the effects of drugs and spices, to the characteristics of illnesses and to the temperament of human beings. By the Renaissance,

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[130] 'Figura est vas vitreum quo facillime possumus singulis horis dimetiri temperaturam frigidam, vel calidam et perfecte scire singulis horis quantum temperatura recedat a naturali statu prius mensurato. Quod vas ab Herone in alium usum proponitur. Nos vero illud accomodavimus, et pro dignoscendua tempratura calida et frigida aeris, et omnium partium corporis, et pro dignoscendo gradu caloris febricitantium.' I quote here from a later edition of the work: S. Santorio, *Commentaria in primam fen primi libri Canonis Avicennae* (Venice: 1646) c. 30–31.

[131] Santorio S., *Canonis Avicennae* c. 307–310.

[132] Santorio S., *Canonis Avicennae* c. 107–110.

[133] The following overview is based on: Maclean I., *Logic, signs and nature in the Renaissance* (Cambridge: 2002) 171–190; Sylla E., "Medieval quantifications of qualities: the 'Merton School'", *Archive for history of exact sciences*, 8 (1971) 9–39.

complex systems of classification and manipulation of degrees, among them those of hotness and coldness, had been developed.

This means that Santorio, when he used the inverted-glass experiment to estimate the "temperature" of a patient, was operating within a very well defined theoretical framework, shared by many and known to all natural philosophers, including those who did not embrace Aristotelianism. Within Santorio's world view, the inverted-glass experiment found its place not as a demonstration of hitherto unknown secrets of nature, but as the operationalisation of a pre-existing theoretical model. Santorio's instrument presented a remarkable similarity to modern scientific instruments, in that not the device itself, but only its *quantitative readings* were supposed to be observed.

Santorio's description of temperature measurement looks deceptively similar to a modern one largely because, as already noted, the vocabulary is the same. Yet Santorio's "temperature" was not the modern one. For Santorio, the reference point for measuring the temperature of a body was the "temperate state" of that same body, i.e. the state in which hot and cold balanced each other exactly. Thus, in Aristotelian-Galenic terms, a healthy human body, a healthy animal and a temperate climate would all have had the same Aristotelian-Galenic "temperature": a temperate one. It is not by chance that the "temperature" of human blood remained a fixed point.

Gianfrancesco Sagredo and Non-Aristotelian Degrees of Heat and Cold

In the Bibliotheque de l'Arsenal in Paris, a manuscript containing a collection of mathematical marvels is preserved.[134] The author's name is Bartolomeo Telioux and the title of the collection is: 'Marvellous mathematics, wherein are to be seen the more beautiful and delightful devices of pneumatics, military engines, [...]'. It is dated: Rome, 1611.[135] In the seventeenth century, the diffusion of collections like this

[134] The following discussion is based on: Caverni R., *Storia*, vol. 1, 284; Chaldecott J.A., "Bartolomeo Telioux and the early history of the thermometer", *Annals of science*, 8 (1952) 195–201 and plates X–XI; Libri G., *Historie des sciences mathématiques en Italie, depuis la Renaissance des lettres jusqu'a la fin du dix-septième siècle*, vol. 4 (Paris: 1841) 471–472; Middleton W.E.K., *Thermometer* 11–12.

[135] The title page and the two pages of the manuscript relevant to the history of the thermometer are reproduced in Chaldecott J.A., "Bartolomeo Telioux" fig. 2 and fig. 3, from which I quote: 'Matematica maravigliosa che si veddono li più vaghi et

was similar to that of books on the secrets of nature in the sixteenth century. One of the marvels included in the collection is: 'An instrument composed by two phials with which one can know the changes in weather ('tempo') in hot or cold in degrees or minutes'.[136] The instrument is shown in a drawing as a set-up similar to, but not identical with, that of the inverted-glass experiment. The device was made out of two long-necked glass flasks, one of which was inverted so that its neck would fit into that of the other one. The length of the (now common) neck was graduated from one to eight. The text and drawing are somewhat at odds with one another and have been often discussed in the literature, but I shall not repeat the argument here.[137] While the details of the device are not especially relevant here, it is important to notice that already in 1611, one year before the publication of Santorio's work, an instrument to measure degrees of heat and cold in the air was presented as a mathematical curiosity and was not explicitly linked to Aristotelian-Galenic tradition. Thus, I have translated the term 'tempo' as 'weather', even though at the time it might have been intended rather as "temper of the air" in an Aristotelian-Galenic sense.

While Telioux provides a first hint, the best evidence of how easily temperatures and degrees of heat and cold could adapt to a non-Aristotelian context can be found in the correspondence of Galileo Galilei. Once again, it is an exchange of letters in which those by Galileo himself are missing and only those of his correspondent, Giovanfrancesco Sagredo (1571–1620), remain.[138] Sagredo was a Venetian gentleman and a close friend of Galileo. During many years, he worked with the glass makers of Murano to provide Galileo with glass instruments, especially lenses. On June 30th, 1612, i.e. a few months after Galileo had corresponded with Antonini on Drebbel's "perpetuum mobile", Sagredo wrote to him that a friend of his had been in Padua and had seen Santorio's instrument 'with which one could measure cold and heat

dilettevoli artifici dell pneumatico, manganaria [...] in Roma MDCXI' (Chaldecott J.A., "Bartolomeo Telioux" fig. 2).

[136] 'Instrumento composto da due fiale col quale si conosce il cambiamento del tempo in caldo o in freddo secondo gradi o minuti' Chaldecott J.A., "Bartolomeo Telioux" fig. 3.

[137] The question is sketched in Middleton W.E.K., *Thermometer* 11–12. Anyway I agree with Caverni's explanation that it responded to expansion of the air in the lower bulb, like the device described by Beeckman I., *Journal*, vol. 2, 237.

[138] What little is known about Sagredo is summed up in Galilei, *Opere*, vol. 20, 528. Sagredo's letters on the thermometer are discussed in Caverni R., *Storia*, vol. 1, 275–278; Middleton W.E.K., *Thermometer* 6–8; Taylor F.S. "Origin" 141–142.

with a compass'.[139] The friend had given a description of the device, and Sagredo's reaction had been identical to that of Antonini: he had made a copy. In fact, he made many copies of it, and even explained to Galileo how much each piece had cost him.[140]

We may speculate as to why Sagredo made so many copies of the instrument: possibly he, too, wanted to give them as valuable presents. In any case, his enthusiasm for thermometry turned out to be lasting: over the next three years, he wrote to Galileo, explaining how he had been developing and employing new forms of the device. From Sagredo's remark, we understand that Galileo was advising him and also probably experimenting himself. Interestingly, though, there is virtually no trace of Galileo's activity left. Sagredo, instead, reported his experiments with enthusiasm, writing that his instruments were now so perfect, that 'the difference in temperature between one room and the other can be seen up to 100 degrees'.[141] He noted 'that in winter, air is colder than ice or snow and that now water appears colder than air […] and similar subtleties which the Aristotelian could not explain'.[142] In 1615, he could use the instrument to compare the degrees of cold reached in that winter with those of the previous ones.[143] Although Sagredo used the Aristotelian vocabulary of temperatures, temperaments and degrees, he held nothing of Aristotelian theories on the subject and speculated on the causes of the effects he saw in the instruments, asking Galileo for advice.[144] The Venetian gentleman was also the first to build himself a number of devices with the same form, but different dimensions, in such a way that he could say 'since almost three years, they work with such proportion between each other, that it is a marvel.'[145]

In conclusion, Sagredo had taken over both the instrument and the vocabulary of the Aristotelian-Galenic Santorio, while at the same time

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[139] 'col quale se misurava il fredo et il caldo col compasso' Galilei, *Opere*, vol. 11, 350.

[140] Galilei, *Opere*, vol. 11, 350–351.

[141] 'la differenza della temperie di una stanza all'altra si vede fin 100 gradi.' Galilei, *Opere*, vol. 11, 506.

[142] 'che l'inverno sia più freda l'aria che il giaccio et la neve, che hora appari più freda l'aqua che l'aria, […] et simili sottigliezze, alle quali i nostri Peripatetici non sanno dar nessuna rissolutione.' Galilei, *Opere*, vol. 11, 506.

[143] Galilei, *Opere*, vol. 12 (Firenze: 1968) 140.

[144] Galilei, *Opere*, vol. 12, 157–158.

[145] 'già quasi tre anni lavorano con tanta proportione tra di loro, che è meraviglia.' Galilei, *Opere*, vol. 12, 169.

questioning the relevant theories and trying to give a new philosophical meaning to the degrees shown by the device.

The Dutch Weatherglass

Drebbel's "perpetuum mobile", like the set-up for the inverted-glass experiment, could in principle detect changes both in temperature and in atmospheric pressure. The latter, as is well known today, are a rather good indicator of weather changes.[146] The discovery of air pressure is usually regarded as having taken place around 1650, although, as we have seen, the phenomenon itself had been exploited by engineers long before that. By the middle of the seventeenth century, the apparent connection between variations of the air-pressure and weather changes and its possible causes was a subject of dispute.[147] Only in the early nineteenth century could the connection be explained in terms of a more general theory.[148]

However, even before the phenomenon of the spring of air had been conceptualised, someone had noticed the relationship between weather changes and variations of the position of water in Drebbel's "perpetuum mobile" or in the inverted glass. While we have no evidence of this person's identity, we know that the discovery was made in the early seventeenth century, very likely in the Netherlands.

The earliest indisputable evidence of the knowledge of the weather-forecasting capabilities of a water-in-glass instrument can be found in a document written in 1619, preserved in the Royal Archives of Gent.[149] The document says that the wife of the engineer Ghijsbrecht de Donckere had sold to the Collegium:

> […] a certain instrument, newly invented by her husband and called "motus perpetuus", with which it is possible to see everyday, through the rising of the water, bad weather, through the falling of the water,

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[146] On air pressure in modern meteorology and its importance for weather forecasts: Häckel H., *Meteorologie* 37–43.

[147] Golinski J., "Barometers" 72–77.

[148] Fierro A., *météorologie* 99–100.

[149] The following discussion is based on Bolle B., *Barometers* (Haarlem: 1978) 74–77, text printed on 75–76.

> instead, the weather calming down, and, when the water rises very high and drops come out, that there will be storm at sea.[150]

A second document tells us that later on, in 1621, Donckere was paid by the city of Bruges for his weather-forecasting "perpetuum mobile".[151] We note that, here, the water went up with bad weather, i.e. with low air pressure. In the set-up for the inverted-glass experiment, water would in that case instead go down, and this suggests that Donckere's device must have rather resembled the J-shaped tube which, according to Henri de Heer and Jan Baptista van Helmont, was sold in Liège in the 1620s.

Thus, it is certainly possible that observers of Drebbel-style perpetual motion were also aware of its weather-forecasting capabilities, a feature that would certainly have made the device even more fascinating in the eyes of spectators. The historian Henri Michel was rightly astounded to find a reference to barometric weather forecasts so early, but other historians of science have taken little notice of it, overlooking its significance. Yet, recognition of the water-weather connection is a anything but trivial and can happen only under very specific conditions. First of all, a set-up similar to Drebbel's perpetual motion or to the inverted-glass experiment has to be kept undisturbed for a rather long period of time. Second, the set-up must be observed regularly, noting the changes in water level. Finally, weather conditions must also be kept under scrutiny: it is only at this point that the discovery becomes possible. Of course, the connection might still go unnoticed.

Possibly, the commercialisation of Drebbel-style perpetual motion devices contributed to the discovery of their weather-forecasting properties, since these objects were made to be set up and then left undisturbed to move by themselves. In any case, devices of this kind remained a commercial success for a long time, at least in some parts of Europe: there is ample evidence that, from the second half of the seventeenth century until the nineteenth century, devices of this kind

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[150] 'zeker instrument, nieuwelijnghe bij denzelven haeren man gheinventeert, ghenaempt motus perpetuus, bij dewelcke men door het upclimmen van het water daghelicx can zien de ruijdachticheijt van het weder, metghaders door het nederdalen het verzoeten van het wedere, ende door het te zeer hooch climmen ende brobbelen de anstaende tempeesten van de see.' (Bolle B., *Barometers* 75).

[151] This second document is quoted and discussed in Bolle B., *Barometers* 76 and also in Michel H., "Mouvement perpetuel" 293–294.

were produced by glass makers in the Low Countries.[152] In Dutch, the instrument eventually became known as "donderglas" ("thunderglass"), in French as "baromètre liégeois" ("barometer of Liège").

The End of Anonymity: Francis Bacon's 'vitrum calendare' and Giuseppe Biancani's 'thermoscopium'

In the year 1620, two works were printed, which not only described how to use the set-up for the inverted-glass experiment to measure degrees of heat and cold, but also gave it a new name. The books were Francis Bacon's *New Organon* and Giuseppe Biancani's *The sphere of the world*.[153] In both works, for the first time, the apparatus was indicated with a specific name: Bacon called it a 'vitrum calendare', Biancani a 'thermoscopium'. As we shall see, perhaps the most determining step in the early history of the thermometer was its naming.

In his long investigation of the 'form of heat' ('forma calidi') in book 2 of the *New organon*, Francis Bacon described a device derived from the set-up for the inverted-glass experiment and used it to demonstrate the sensibility of air to heat: "Among all bodies known to us, air is the one which most easily absorbs and emits heat, and this can best be seen in calendar glasses ('in vitris calendaris')".[154] The term 'vitrum calendare' appears here for the first time.

Bacon's description differs from the many we have read only in that he advised the reader to fix the neck of the inverted glass to the mouth of the water vessel with some wax, so that it would easily remain standing. With this little addition, a temporary experimental set-up was transformed into a more or less permanent device: the 'vitrum calendare'. Bacon also suggested fixing a graduated strip of paper to the neck of the flask, to better observe how air would expand and contract. For him, the instrument measured the degrees of the air's sensitivity to heat and cold: here, too, air and its properties, and not simply heat and cold, were what was being observed in the glass. However, Bacon did

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[152] Bolle B., *Barometers*, pp. 76–77; Michel H., "Le baromètre liégeois", *Physis* 3 (1961) 203–212.

[153] Francis Bacon, *Neues Organon: lat.-deutsch*, ed. W. Krohn, 2 vols (Hamburg: 1990) 344–346; Biancani's work was originally published in 1620, but I have used the reprint of 1653: Giuseppe Biancani, *Sphaera mundi, seu cosmographia* (Modena: 1653) 54–55.

[154] 'Facillime omnium corporum apud nos et excipit et remittit calorem aer; quod optime cernitur in vitris calendaris', Bacon, *Neues Organon*, vol. 2, 344.

not believe that the device demonstrated a particular, intrinsic activity of air, but only its sensitivity to heat. In his *History of the dense and the rare (Historia densi et rari)*, posthumously published in 1658, he proposed substituting water with spirit of wine, to test whether air would also react to alcohol's 'potential heat' ('calor potentialis'), like animal spirits did.[155] In his *Forest of forests (Sylva sylvarum)* (1627), instead, he suggested using a weatherglass to test whether air would be sensitive to the cold of opium, although he doubted that the experiment would succeed.[156] These remarks show clearly how broad Bacon's concept of heat and cold was, much nearer to the Aristotelian-Galenic one and not yet defined through the reaction of the thermometer.

Bacon did not in any way suggest that he had invented the term "vitrum calendare". Quite the contrary, he uses it in a generic plural form, which seems to imply that he was referring to well-known instruments. Therefore, we might conclude that, already in 1620, devices named "weatherglasses" were circulating in England, and it also seems probable that their sensitivity to weather changes was known, even if Bacon did not mention it.

Giuseppe Biancani (1566–1624) was a Jesuit mathematician teaching at the Gymnasium in Parma. His work was not only firmly grounded in Aristotelian tradition, but was also explicitly aimed at defending it against other world views.[157] In 1620, Biancani published the *Sphere of the world, or cosmography (Sphaera mundi, seu cosmographia)*, an anti-Copernican textbook of astronomy intended for his students. In the part of this book devoted to the movement of air, Biancani offered an image and a description of Santorio's instrument for determining degrees of heat and cold, introducing it with these words:

> Air also has another motion, through which the same air sometimes escapes less or more or increases and diminished its volume, and this without anything being done from the outside; physicists call this rarefaction

[155] Francis Bacon, "Historia densi et rari (Rawley's version)", in Francis Bacon, *The Instauratio magna: last writings*, ed. G. Rees (Oxford: 2000) 35–169, here 106–108.

[156] Francis Bacon, "Sylva sylvarum", in Francis Bacon, *Works*, vol. 2, 331–680, here 371 (par. 74). The weatherglass is mentioned also in par. 27 (Bacon, "Sylva sylvarum" 348).

[157] My overview of Biancani's life and work is based on: Grillo E., "Giuseppe Biancani", *Dizionario biografico degli Italiani*, 10 (1968) 33–35.

> and condensation. This is demonstrated in many experiments, and it seems fit to describe here the most beautiful and evident of them.[158]

Here followed a description of the inverted-glass experiment, performed using coloured water. At the end, the author added:

> With the help of this instrument, which I would like to call thermoscope ('thermoscopium'), it is possible to investigate many questions relative to the nature of air. I heard that its inventor is a doctor living in Padua, called Santorio.[159]

The term 'thermoscopium' appears here for the first time and Biancani suggests he coined the term. The term was clearly modelled after "telescopium", a neologism that had been proposed less than a decade earlier, in 1611.[160] Biancani, like Bacon, linked the instrument to the possibility of investigating air, but he, too, did not find air's reaction to heat particularly remarkable. Instead, he gave the device a name describing the use Santorio had put it to: visualising heat.

Biancani had probably not read Drebbel's work, though he might well have heard of his machine. Della Porta's book on the *Transmutations of the air*, though, was known to him, because he quoted it in the paragraph just preceding that of the thermoscope.[161] Though Biancani's discussion of the thermoscope ignores the use Della Porta had made of that same device, I believe it was Della Porta's meteors he had in mind while writing these passages. Firstly, he included the thermoscope in the treatment of the movement of air. Furthermore, in the paragraph following the discussion of the thermoscope, he refers to the question of the origin of winds, curtly stating: 'The movement of winds has nothing to do with astronomy, and therefore shall have to be left to the disquisitions of the philosophers.'[162]

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[158] 'Inest alius aeri motus, quo idem aer aliquando minor, aliquando maior evadit, seu suam auget et minuit magnitudinem, idque nullo extrinsecus additamento; hunc physici rarefactionem et condensationem appellant, quod etsi multis constet experientiis, libet tamen pulcherrimam nunc aeque ac evidentissimam afferre.' Biancani, *Sphaera mundi* 54.

[159] 'Auxilio huius instrumenti, quod ego thermoscopium libenter appellarem, multa ad aeris naturam spectantia indagari possunt, audivi doctorem quendam medicum Patavii degentem, qui Santorius cognominatur huius esse inventorem.' Biancani, *Sphaera mundi* 55.

[160] King H.C., *The history of the telescope* (New York: 1955 repr. 1979) 38.

[161] Biancani, *Sphaera mundi* 54.

[162] 'Ventorum agitatio nihil astronomicum sapit, ideo philosophicis disquisitionibus reliquenda est.' Biancani, *Sphaera mundi* 55.

The Thermometer as a Mathematical Instrument

In 1622, the Jesuit college of Pont-à-Mousson published a collection of mathematical problems (*Selected propositions*) that had been debated during the celebrations for the day of St. Xavier and Ignatz.[163] The book was written in Latin, in a very concise and at times rather cryptic style. It was anonymous, but the Jesuit emblem on the front page made it clear that it had been written by a member of the College. Later, editorship of the book was ascribed to the Jesuit mathematician Jean Leurechon (1591–1670).[164]

In the *Selected propositions* we find the second mention of the term 'thermoscopium' in print. The list of the subjects to be discussed in the problems of mechanics includes a demonstration of 'the temperature of air in different times and places in the thermoscope'.[165] However, the instrument does not appear anymore in the following pages.

In 1624, another collection of mathematical divertissements was printed in Pont-à-Mousson: the *Mathematical recreation composed of various entertaining and witty problems*.[166] It was in this work that the word thermometer appeared for the first time.

The *Recreation* was written in French in a very pleasant, clear and easily understandable style and it did not bear on the front page the emblem of the Jesuits. The name of the author appeared only as a signature to the dedication: 'H. van Etten'. However, this book, too, was later listed among the works edited by Leurechon. This attribution has been alternatively accepted and refuted by historians, who even raised doubts as to the actual existence of H. van Etten. Recently, historians accepted Thomas Hall's thesis that the author of the work was really a man called van Etten, whom Hall identified as a student of Leurechon.[167] Whether the editor of the *Recreation* was Leurechon himself, a

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[163] *Selectae propositiones in tota sparsim mathematica pulcherrimae, quas in solemni festo sanctorum Ignatii et Xaverii et annivesaria collegii mussipontani celebritate literaria propugnabant mahematicarum auditores* (Pont-à-Mousson, 1622).

[164] Article: "Jean Leurechon", *Bibliothèque de la Compagnie de Jésus. Nouvelle Edition. Bibliographie*, vol. 4 (Bruxelles-Paris: 1893) c. 1755–1761.

[165] 'aeriam temperiem pro diversis temporibus et locis in thermoscopio' *Selectae propositiones* 10 (mech. II).

[166] van Etten H., *Recreation mathematique composee de plusieurs problemes plaisants et facetieux* (Pont-à-Mousson, 1624). On the German adaptation of this work written by Daniel Schwenter and Georg Philipp Harsdörffer see the contribution of Berthold Heinecke in this volume.

[167] Eamon W., *Secrets of nature* 420–421 n. 29); Gronemeyer N., *Optische Magie. Zur Geschichte der visuellen Medien in der Frühen Neuzeit* (Bielefeld: 2004) 136.

student of his or whether the book was the result of a collaboration, the work was closely linked to Jesuit circles. This fact is confirmed by the similarities between the work of 1622, which was undoubtedly of Jesuit origin, and the *Recreation* of 1624, a similarity already noted by Gustav Hellmann.[168] Even though the language, style and structure of the two works are completely different, the contents of some of individual problems are very closely related to each other. For example, some problems of arithmetic are formulated in the same terms, and even use the same numbers.[169] Moreover, the list of subjects given in the introduction of the *Recreation* is almost identical to the index of the *Selected propositions*.[170] The 'Recreation' rapidly became an international success and was reprinted, enlarged, translated and adapted to many other languages by later authors.[171]

Books of mathematical entertainments, describing arithmetical and geometrical puzzles, mechanical devices and offering curious information of various kind, became very popular in the early seventeenth century.[172] This kind of literature was very influential on European "virtuosi", transforming mysterious experiments in natural magic into entertaining tricks. In this sense, mathematical entertainments conformed to the Jesuit idea of spreading faith through science. This might also explain why Leurechon would have had an interest in publishing the book anonymously, since a Jesuit emblem on the front page might have hindered the diffusion of the work in non-catholic lands. Perhaps the best proof of the effectiveness of this approach is the fact that it was in large part thanks to the success of the *Recreation* and of its later enlarged versions that the term "thermometer" became rapidly known in all Europe.

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168 Hellmann G., "Erfindungsgeschichte" 14–15.

169 For example, numbers like 244 140 625 000 000 000 000 or 611 351 562 500 00, respectively in *Select propositions* 5 (arit. XI) and van Etten H., *Recreation mathematique composee de plusieus problemes plaisants et facetieux* (Pont-à-Mouson: 1626) 113–114 (87.III) (I have used the second edition of the 'Recreation') Other problems similar to each other are: *Selected propositions* 5 (arit. XII, XIII) and van Etten H., *Recreation* 112–114 (87.II, 87.X).

170 Both in the *Selected propositions* and van Etten H., *Recreation* the lists are given in the initial pages, which are not numbered. In the *Selected propositions* we find: 'Arithmetica, geometrica, mechanica, cosmographica, musica, optica', in van Etten H., *Recreation*: 'Arithmetique, geometrie, mechanique, optique, musique, cosmographie.'

171 The article: "Jean Leurechon", *Bibliothèque de la Compagnie de Jésus* lists many of the later translations and adaptations.

172 Eamon W., *Secrets of nature* 306–311; Gronemeyer N., *Optische Magie* 136–153.

In the *Recreation*, a whole problem was devoted to the 'thermometre'.[173] The title of the section was: 'On the thermometer, or instrument to measure the degrees of heat or cold which are in the air.'[174] Two forms of the thermometer were described and also shown in a picture. The first one corresponded to the set-up of the inverted-glass experiment. The second was a J-shaped tube, whose lower extremity ended in an enlarged belly, open to the air and filled with water. According to the image, the tube was fixed onto a wooden stand with a graduated scale going from 1 to 9.[175] This was the same device as the one being sold to the inhabitants of Liège in the 1620s, according to de Heer and van Helmont, and possibly also in Italy, as Marsili's letter to Galileo suggests. However, the text of the *Recreation* said nothing about tides or weather predictions. Instead, it explained in much detail that the thermometer worked because air expanded and contracted with heat, and that it could be used to learn the degree of heat or cold in the air, comparing not only one room to another, but also morning and evening, or one day to the next. Moreover, the strength of fevers could be measured. To quantify the results, the thermometer could be provided with a scale of four or eight degrees, according either to the physicians or to the philosophers. Again, one can recognize here the heritage of Aristotelian-Galenic scales of four plus four degrees, even though there is absolutely no mention of the ancient philosophers in the text.

In describing the thermometer and its use, the author of the *Recreation* was not simply demonstrating a curiosity, but was offering an explanation for the behaviour of various devices circulating in that period, purportedly demonstrating the activity of air. The author of the book defined all such devices as "thermometers", and thus assimilated them to mathematical instruments, i.e. tools whose working principles were perfectly known, and which helped measure various physical quantities. In 1629, yet another Jesuit, Niccolò Cabeo (1585–1650) explicitly characterized Drebbel's "perpetuum mobile" as a "thermoscopium", stating that the device maintained its utility even though its secret had now been discovered.[176]

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[173] I shall quote from the 1626 edition of the work: van Etten H., *Recreation* 75–76 (par. 76).

[174] 'Du thermometre, ou instrument pour mesurer les degrez de chaleur ou de froidure, qui sont en l'air' (van Etten H., *Recreation* 75).

[175] The plate with the image is bound in van Etten H., *Recreation* between pages 68 and 69.

[176] Drake-Brockman J., "perpetuum mobile" 14–142.

In conclusion, it is plausible that the origin of the word "thermometer" can be sought in Jesuit circles, particularly among Jesuit mathematicians. Almost immediately, however, both the word "thermometer" and the Aristotelian terms "temperature" and "degree of heat and cold" became part of a hybrid vocabulary shared by philosophers of all schools of thought.

Pneumatic versus Mechanic Technology?

The importance of the naming of the thermometer can hardly be underestimated. "Thermoscope" and "thermometer" were much more than new labels for pre-existing instruments: they were, in a sense, definitions, stating the function of the object to which they referred. The thermometer was an instrument to measure heat, and all its other features were thus effectively put out of focus, in particular the activity of the air. Seen through this filter, the inverted-glass experiment became the earliest form of the thermometer and, within a few decades, the same name could be applied to the thermometers of the Accademia del Cimento, which measured heat through the expansion and contraction of spirit-of-wine. Unlike Biancani's and van Etten's thermometers, these instruments did not – could not – demonstrate the activity of the air, and neither could they help predict the weather.

However, as the material discussed has shown, in the 1630s there was no clear-cut distinction between weatherglass, thermometer and "perpetuum mobile". All these aspects were perceived by each observer of the same instrument, even though he might eventually chose to concentrate only on those features that most appealed to his own world view. Bacon spoke of measuring the air's sensitivity to heat, but used the term "weatherglass". Sagredo used the vocabulary of Aristotelianism to dispute its theories. Biancani spoke of measuring Aristotelian temperatures like Santorio had done, but probably had Della Porta's discussion of the origin of wind in mind. The author of the *Recreation* described how entertaining the instrument could be, and astutely left its interpretation to his readers.

It is important to stress once again that all features of the weatherglass/thermometer were in principle well worth attention. The measure of heat and cold was certainly a good reason to regard thermometers as interesting from the natural philosophical point of view, but also the question of why the air reacted to heat and cold, as well as its

capability of responding to weather changes were of great potential interest. Because of the many different philosophical viewpoints, which not only competed, but often also complemented each other in early seventeenth-century Europe, there was no clear-cut distinction between weatherglass and thermometer. Moreover, there is no reason to believe that such a distinction established itself shortly afterward.[177] We have already seen how Drebbel's perpetual motion machine continued fascinating audiences for many decades, and how Dutch weatherglasses, whose main function was to help predict weather, were produced and perfected from the seventeenth century onward. In 1636, when the *Recreation* was translated into Latin, the term 'instrumentum Drebelianum' was added to the name thermometer and, as we have already seen, the name of Drebbel remained linked to the thermometer at least until the late eighteenth century.[178] The story of the thermometer has often been told, that of the weatherglass has rather been forgotten. However, in the 1630s, the latter was probably more popular than the former, at least in some countries.

In the 1630s, weatherglasses were being made and sold in England as well: in his *Mysteries of nature and art* (1634), a collection similar to the *Recreations*, but more instrument-oriented, the instrument-maker John Bate (fl. 1634) discussed more than seven variants of the weatherglass.[179] He also explained at length its weather-forecasting properties:

> Albeit the formes of weather-glasses are divers, according to the fancy of the artist, yet the use of all is one and the same: to wit, to demonstrate the state, and temper of the season, whether hot or cold, and also to foreshow the change and alteration thereof.
> 1. Note therefore, that the nature and property of the water in all the glasses that have no vent holes at the top, is, to ascend with cold, and descend with heat. But in them that have vents, it descendeth as much as it ascendeth in these.
> 2. The sudden falling of the water is an evident token of rayne.
> 3. The continuance of the water at any one degree, is a certaine token that the weather will continue at that stay it is then at, whether it be fayre, or foule, frost or snow. But when the water either riseth or falleth, the weather will then presently change.
> 4. The uncertain motion of the water is a signe of fickle weather.

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177 In fact, there is evidence to the contrary: Castle T., *The female thermometer. Eighteenth-century culture and the invention of the uncanny* (New York-Oxford: 1995) 21–43.

178 Wohlwill E., "Erfindung" 163–164.

179 Bate J., *Mysteries of nature and art* (London: 1634) 28–39. On Bate and his work, see Eamon, *Secrets of nature* 307.

> [...] These rules are all certain and true: now you may according to your owne observation frame other rules, whereby you may foretell the change of the weather the water being at any one degree whatsoever.[180]

It was precisely in these years that Robert Fludd chose the weatherglass to represent all aspects of his cosmology.[181] Fludd mentioned the weatherglass first in 1617, but it was especially in the *Whole mistery of diseases (Integrum morborum mysterium)* (1631) and in the *Mosaical philosophy (Philosophia Mosayca)* (1638) that the instrument became, as Allen Debus noted, 'a key to two worlds', i.e. microcosmos and macrocosmos. In Fludd's cosmology, meteors, especially winds, played a central role, and his theory of meteors is very similar to those of Drebbel and Della Porta. The heat of the sun, which was of divine origin, acted on the element air, infusing it with the spirit of life. This spirit was spread by air to the creatures living on earth. Fludd considered the four winds as the instrument with which God acted on the sublunary world.[182] In this context, the weatherglass not only demonstrated the origin of winds, but also embodied all correspondences between microcosmos and macrocosmos in a way which it would be impossible to summarize here.

Significantly, in his *Mystery of disease's* Fludd reproduced Drebbel's image of the inverted-glass experiment.[183]

In his *Mosaical Philosophy*, translated into English in 1659, Fludd explained that he had chosen the weatherglass as a visual demonstration of his doctrines because it was a well-known device:

> I will make therefore election of such demonstrative machine for my purpose as is vulgarly known amongst us, hereby my intentions may be more easily understood of every man.[184]

Fludd explained the principles according to which the weatherglass functioned as contraction 'when the included aire is animated by the externall cold' and expansion 'if the included spirit be excited by any

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[180] Bate J., *Mysteries* 38–39.

[181] The following overview is based on: Debus A.G., "Key to two worlds: Robert Fludd's weather-glass", *Annali dell'istituto e museo di storia della scienza di Firenze*, 7 (1982) 109–143; Debus A.G., *Chemical philosophy*, vol. 2, 205–293; Debus A.G., *English Paracelsians* 101–127.

[182] Debus A.G., "Key to two worlds" 126–127.

[183] Robert Fludd, *Integrum morborum mysterium: sive medicinae catholicae tomi primi tractatus secundus* (Frankfurt: 1631) 462.

[184] I quote from the English translation: Robert Fludd, *Mosaicall philosophy grounded upon the essential truth, or eternal sapience* (London: 1659) 2.

externall heat'.[185] He also gave instructions on how to use the weatherglass to predict weather, and they were similar to those printed by John Bate.[186] Fludd's reflections were an original development of previous Paracelsian theories, which he supported through new discoveries not only in meteorology, but also concerning the relationship between blood circulation and respiration as well as between air and combustion.

In his work, he fully exploited the explanatory potential of the weatherglass – in fact, well beyond its limits – and gave great relevance both to alchemy and to pneumatics, filling the pages of the *Mistery of diseases* with images and descriptions of Heronian instruments.[187]

By contrast, Descartes never even mentioned in his work weatherglasses or thermometers and instead made large use of mechanical automata in his explanations.[188] Once again we see how, in the early seventeenth century, each philosophy chose its own, favourite technology.

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[185] Fludd, *Mosaicall philosophy* 6.

[186] Fludd, *Mosaicall philosophy* 6–7.

[187] See for example: Fludd, *Integrum morborum mysterium* 420–476.

[188] I base this statement on the fact that no quote by Descartes appears in histories of the thermometer, and it is highly improbable that it would have escaped notice.

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PART II

BACON: MECHANICS, INSTRUMENTS AND UTOPIAS

THE ROLE OF MECHANICS IN FRANCIS BACON'S *GREAT INSTAURATION*

Sophie Weeks

> Very beautiful again is that allegory of the labyrinth; under which the general nature of mechanics is represented. For all the more ingenious and exact mechanical inventions may, for their subtlety, their intricate variety, and the apparent likeness of one part to another, which scarcely any judgment can order and discriminate, but only the clue of experiment, be compared to a labyrinth. Nor is the next point less to the purpose; viz. that the same man who devised the mazes of the labyrinth disclosed likewise the use of the clue. For the mechanical arts may as it were be turned either way, and serve as well for the cure as for the hurt, and generally their virtue unravels and unwinds itself.[1]

1. *Introduction*

Since the publication of Paolo Rossi's brilliant *Francis Bacon: From Magic to Science*, the inclusion of the mechanical arts in Bacon's programme has been widely acknowledged.[2] Yet little attention has been given to the role of mechanics in Baconian inquiry. Two related explanations for

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[1] My modification, Francis Bacon, *De sapientia veterum*, in *The Works of Francis Bacon* (hereafter abbreviated as *SEH*), eds. J. Spedding – R.L. Ellis – D.D. Heath, 7 vols (London: 1859–64) vol. 6, 735, cf. 660. 'Pulcherrima autem allegoria est de labyrintho, qua natura generalis Mechanicæ adumbratur. Omnia enim mechanica, quæ magis sunt ingeniosa et accurata, instar labyrinthi censeri possint; propter subtilitatem et variam implicationem, et obviam similitudinem, quæ vix ullo judicio, sed tantum experientiæ filo, regi et discriminari possunt. Nec minus apte adjicitur, quod idem ille qui labyrinthi errores invenit, etiam fili commoditatem monstravit. Sunt enim artes mechanicæ veluti usus ambigui, atque faciunt et ad nocumentum et ad remedium, et fere virtus earum seipsam solvit et retexit.'

[2] Rossi P., *Francesco Bacone: dalla magia alla scienza* (Bari: 1957); transl. by S. Rabinovich as *Francis Bacon: From Magic to Science* (London: 1968) 1–35. See also idem, *I filosofi e le macchine* (Milan: 1962); transl. by S. Attanasio as *Philosophy, Technology, and the Arts in the Early Modern Era* (New York: 1970) 100–136, 137–145, 146–173; Idem, "Bacon's Idea of Science", in Peltonen M. (ed.), *The Cambridge Companion to Bacon* (Cambridge: 1996) 25–46. B. Farrington also drew attention to Bacon's inclusion of the mechanical arts in *Francis Bacon: Philosopher of Industrial Science* (London: 1951) 3–18, 92–113; Idem, *The Philosophy of Francis Bacon* (hereafter abbreviated as *BF*) (Liverpool: 1964) 32–34.

this oversight in Baconian scholarship present themselves. First, many commentators fail to distinguish between programmatic aims and inquisitional detail in Bacon's works. Second, Bacon's classification of three kinds of mechanics—the mechanics of the artisan, *experientia literata*, and what I refer to here as 'philosophical mechanics'—has been utterly overlooked.[3] Accounts of Bacon's programmatic aims and broad brushstroke historical analyses perforce take little account of the complexity of Baconian inquiry and of the place of mechanics within it. Consequently, Bacon is misleadingly characterised as spearheading a general cultural shift which succeeded in elevating the status of the mechanical arts in the burgeoning growth of early modern natural philosophy.[4] Although Rossi's pioneering studies highlighted Bacon's appraisal of the mechanical arts, the function of mechanics within Baconian inquiry has not been adequately investigated. In addition, there is the key question of why Bacon designates the goal of his Instauration 'true NATVRALL MAGICKE.'[5] Bacon believes that his programme will achieve what the magical and alchemical traditions have attempted haphazardly. He does not claim to possess a wholly new species of transformative power; the radical nature of his programme depends only on a novel means of

[3] The term 'philosophical mechanics' is mine, not Bacon's (Bacon simply uses the term 'mechanics'). I use it to avoid confusion with other types of Baconian mechanics, namely, artisanal mechanics and *experientia literata*. Philosophical mechanics depends on knowledge of physical causes. As we shall see in Part 5, only this kind of mechanics (in Bacon's view) belongs to philosophy. See Francis Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 365–366, cf. vol. 1, 571–572.

[4] Following (more or less) the views established by Rossi and Farrington, there is now a substantial literature on changing perceptions of the mechanical arts in the early modern period that include Bacon as a major protagonist. See Ash E.H., *Power, Knowledge, and Expertise in Elizabethan England* (Baltimore: 2004) 186–212; Smith P.H., *The Body of the Artisan: Art and Experience in the Scientific Revolution* (Chicago: 2004); Wolfe J., *Humanism, Machinery, and Renaissance Literature* (Cambridge: 2004) especially 11–14. More general coverage of relevant themes can be found in Engel G. – Karafyllis N.C. (eds.), *Technik in der Frühen Neuzeit. Schrittmacher der europäischen Moderne* (Frankfurt am Main: 2004); Lefèvre W. (ed.), *Picturing Machines 1400–1700* (Cambridge, Mass.: 2004). Bennett J.A. deals with the impoverishment of our historiography through the dismissal of the mechanical arts as 'too mundane and trivial to have had serious "scientific" influence,' in "The Mechanics' Philosophy and the Mechanical Philosophy", *History of Science* 24 (1986) 1–28, on 1. For an older but useful survey which deals with the recovery of a 'Baconian' influence in the commercial expansionism of the eighteenth century see Cochrane R.C., "Francis Bacon and the Rise of the Mechanical Arts in Eighteenth-Century England", *Annals of Science* 12, 2 (1956) 137–156.

[5] Francis Bacon, *Advancement of learning*, in *The Oxford Francis Bacon* (hereafter abbreviated as *OFB*), ed. by G. Rees – L. Jardine, 15 vols (Oxford: 1996), vol. 4, 90.

inquiry based on experimental practice. Mechanics is indispensable in the pursuit of magic because it is essentially experimental. This paper argues that the three kinds of mechanics play distinct but integrated roles in Bacon's 'Great Instauration.'

It is helpful at the outset to clarify certain terms. Bacon's concept of a reformation in natural inquiry is traditionally designated by the term 'method.'[6] This term has come to be associated far too restrictively with an innovation in logical procedure, viz., eliminative induction.[7] I shall therefore use the Baconian term 'inquiry.'[8] The centrally important polysemous term 'experiment' (*experimentum*) refers in a general sense to intervention in nature.[9] The specific Baconian meanings of this term will emerge in due course. Finally, the three kinds of mechanics are treated separately under the headings of 'mechanical history,' '*experientia literata*,' and 'philosophical mechanics.' This re-examination of Bacon's incorporation of mechanics as an inquisitional tool is principally intended to enrich exposition of the Baconian corpus. However, it will also enlarge our understanding of the rise of experimentation and of the role of operative investigation in early modern science.[10]

[6] Rees rightly points out that 'Bacon never used the term [method] in *Novum organum* or anywhere else, to mean "scientific method,"' *OFB*, vol. 11, lxxii. See also Jardine L., *Francis Bacon: Discovery and the Art of Discourse* (Cambridge: 1974) 171–173.

[7] M. Hesse offers a cogent account of the logical aspects of Bacon's method and of Baconian induction, see "Francis Bacon's Philosophy of Science", in B. Vickers (ed.), *Essential Articles for the Study of Francis Bacon* (Connecticut: 1968) 114–139. See also Horton M., "In Defence of Francis Bacon: A Criticism of the Critics of the Inductive Method", *Studies in History and Philosophy of Science* 4, 3 (1973) 241–278.

[8] Bacon uses the term 'inquiry' in the English *Valerius Terminus* (*SEH*, vol. 3, 218, 227, 241, 243, 244, 246, 247, 249). He also uses the term 'inquisition.' On the latter term see Cardwell K.W., "Francis Bacon, Inquisitor", in W.A. Sessions (ed.), *Francis Bacon's Legacy of Texts: 'The Art of Discovery Grows with Discovery'* (New York: 1990) 269–289.

[9] Bacon distinguishes between 'mere experience [*Experientia mera*] which is called accident if it happens by itself, but experiment [*Experimentum*] if it is deliberately sought out' (*Novum organum, OFB*, vol. 11, 131). On the distinction between experience and experiment in Bacon's works see Fattori M., "*Experientia-Experimentum*: Un confronto tra il corpus latino e inglese di Francis Bacon", in Fattori M. (ed.), *Experientia: X colloquio internazionale del Lessico Intellettuale Europeo* (Florence: 2002) 243–258. For an interesting discussion of these terms in the writings of Zabaralla and Galileo see Schmitt C.B., "Experience and Experiment: A Comparison of Zabarella's View with Galileo's in *De Motu*", *Studies in the Renaissance* 16 (1969) 80–138.

[10] The standard work remains Kuhn T.S., "Mathematical versus Experimental Traditions in the Development of Physical Science", in *The Essential Tension: Selected Studies in Scientific Tradition and Change* (Chicago: 1977) 31–65; Anstey P.R. – Schuster J.A. (eds.), *The Science of Nature in the Seventeenth Century: Patterns of Change in Early Modern Natural Philosophy* (Dordrecht: 2005) contains several essays on the emergence and

According to Rossi, 'when Bacon turned to the mechanical arts, considering them capable of revealing the actual processes of nature, and saw in them that capacity to give rise to inventions and works absent in the traditional knowledge [...] he truly became the spokesman for some fundamental demands of the culture of his time.'[11] In Rossi's view, 'Bacon brought to full awareness some of the thematic ideas that had been making slow headway at the margins of the official science in that world of technicians, engineers, and builders to which men like Biringuccio and Agricola had belonged.'[12] Although Rossi is certainly correct that Bacon considered the mechanical arts 'capable of revealing the actual processes of nature,' his generalised historical overview blurs the significance of inquisitional specifics. Bacon distinguishes between the mechanics of artisans and the mechanics of figures such as Agricola. As we shall see, the former he has remitted 'to Natural History, taking it away [*segregamus*] from Natural Philosophy.'[13] Hence Rossi's claim that, 'For Bacon the progress of science [...] required that the knowledge of technicians be integrated into the fields of science and natural philosophy' demands further analysis.[14]

Rossi attributes to Bacon the thesis that 'Knowing is [...] a kind of making.'[15] He argues that this view 'came to its full maturation [...] in the philosophy of the Lord Chancellor.'[16] More recently, Antonio Pérez-Ramos has promoted this idea, portraying Bacon as an exponent of the 'maker's knowledge' tradition: 'a tradition which [...] postulates an intimate relationship between objects of cognition and objects of construction, and regards knowing as a kind of making or as a capacity to make (*verum factum*).'[17] However, the maker's knowledge concept is unhelpful precisely because it conflates distinct phases of Baconian inquiry thus closing off further analysis. The mechanical arts do not

development of the science of mechanics. Of special interest here is P.R. Anstey's essay "Experimental versus Speculative Natural Philosophy" 215–242.

[11] Rossi P., *Philosophy, Technology, and the Arts* 117–118.

[12] Rossi P., *Philosophy, Technology, and the Arts* 118.

[13] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 366, cf. vol. 1, 572. 'verum hanc in Historiam Naturalem conjecimus, a Philosophia Naturali segregamus.'

[14] Rossi P., *Philosophy, Technology, and the Arts* 120.

[15] Rossi P., "Bacon's Idea of Science" 38. See also Idem, *Philosophy, Technology, and the Arts* 146–173.

[16] Rossi P., *Philosophy, Technology, and the Arts* 149.

[17] Pérez-Ramos A., *Francis Bacon's Idea of Science and the Maker's Knowledge Tradition* (Oxford: 1988) 48; Idem, "Bacon's Forms and the Maker's Knowledge Tradition", in Peltonen M. (ed.), *The Cambridge Companion to Bacon* (Cambridge: 1996) 99–120.

educe axioms. In contrast, physics proceeds 'from experiments to axioms,' then philosophical mechanics proceeds from these axioms to 'new experiments.'[18] Bacon's 'route is not laid on the flat but goes up and down—ascending first to axioms, and then descending to works.'[19] Rossi conflates these quite distinct tasks, claiming that they involve 'not two processes but only one, because theoretical research and practical application' are unified and constitute a single means represented under different modes, viz., operation and theory.[20] But (as I discuss in Part 5) Bacon's reference to 'new experiments' shows that he is speaking of two separate processes. On the basis of experiments, physics extracts an axiom; philosophical mechanics must then derive entirely new experiments from this axiom. The concept of maker's knowledge abridges Bacon's inquisitional demands and obscures the role of philosophical mechanics in Baconian inquiry.

Benjamin Farrington's characterisation of Bacon as the philosopher of industrial science is also well known. According to Rossi, 'Farrington's portrait, though basically correct, tends [...] to distort the historical significance of Bacon's attitude.'[21] Yet Farrington does highlight central Baconian themes. For example, he points out the significance of what Bacon calls 'the commerce of the mind with things (*commercium mentis et rei*).'[22] He also observes that 'the contrast between what he [Bacon] calls *natura libera* and *natura vexata* is fundamental in his thought.'[23] However, his portrayal of Bacon as the philosopher of the industrial revolution is misleading. Farrington's famous description of Bacon's programme as 'the marriage between natural philosophy and industrial production' is too simplistic.[24] Like Rossi he fails adequately to explain why Bacon's natural history '*includes, as a major part, the history of the mechanical arts*.'[25] Furthermore, there is no discussion of philosophical mechanics and its contribution to Baconian inquiry.

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[18] Bacon, *De augmentis scientiarum, SEH*, vol. 4, 413, cf. vol. 1, 622–623. '*ab experimentis ad axiomata*, quæ et ipsa *nova experimenta* designent' (italics in orginal).

[19] Bacon, *Novum organum, OFB*, vol. 11, 161. 'Neque enim in plano via sita est, sed ascendendo, & descendendo; Ascendendo primò ad Axiomata, Descendendo ad Opera.'

[20] Rossi P., *Philosophy, Technology, and the Arts* 161.

[21] Rossi P., *Francis Bacon* 10.

[22] Farrington B., *Francis Bacon* 7–8, 14. See Bacon, *Instauratio magna, OFB*, vol. 11, 2.

[23] Farrington B., *Francis Bacon* 94.

[24] Farrington B., *Francis Bacon* 16.

[25] Farrington B., *Francis Bacon* 109 (italics in original).

In *De sapientia veterum* Bacon considers the fable of Dædalus, under whose person 'the ancients drew a picture of mechanical skill [*sapientiam*] and industry.'[26] (See Figure 1.) Dædalus devised both the labyrinth itself and 'that ingenious device of the clue, by which the mazes of the labyrinth should be retraced [*retexerentur*].'[27] As we saw in the epigraph, Bacon interprets the labyrinth as an allegorical representation of 'the general nature of mechanics.' The workings of mechanical contrivances, he says, seem mysterious and impenetrable like a labyrinth on account of their 'subtlety.'[28] However, Bacon elsewhere uses the figure of the labyrinth to signify the current system of nature: 'to the human intellect reflecting on it, the fabric of the universe looks in its construction like a labyrinth, where we find everywhere so many blind alleys, such deceptions and misleading signs and such oblique and intricate convolutions and knots of nature.'[29] In his interpretation of the Dædalus fable, Bacon explains why mechanics plays such a significant role in inquiry. The difference between nature free and nature constrained by art (mechanics) is that whereas the former affords no clue to inquiry, mechanical contrivances are themselves clues. Hence he concludes, in studying artificial things, 'generally their virtue unravels and unwinds [*solvit et retexit*] itself.' For Bacon, all kinds of mechanical practices are experiments. Hence in *Novum organum* he states that experiment 'is like

[26] Bacon, *De sapientia veterum*, in *SEH*, vol. 6, 734, cf. 659. 'Sapientiam atque industriam Mechanicam [...] antiqui adumbraverunt sub persona Dædali [...].' On Bacon's classical sources see Lemmi C.W., *The Classic Deities in Bacon: A Study in Mythological Symbolism* (Baltimore: 1933) 109–118. For insightful commentary on Bacon's acknowledgement of the traditional ambivalence towards the mechanical arts in his interpretation of this fable, see Lampert L., *Nietzsche and Modern Times: A Study of Bacon, Descartes, and Nietzsche* (New Haven: 1993) especially 34–39; Paterson T., "The Secular Control of Scientific Power in the Political Philosophy of Francis Bacon", *Polity* 21, 3 (1989) 457–480; Studer H.D., "Francis Bacon on the Political Dangers of Scientific Progress", *Canadian Journal of Political Science* 31, 2 (1998), 219–234. For an excellent treatment of the relationship between the cultural perception of mechanical contrivances and political and social machination, see Wolfe J., *Humanism, Machinery, and Renaissance Literature* (Cambridge: 2004).

[27] Bacon, *De sapientia veterum*, in *SEH*, vol. 6, 734, cf. 659. 'etiam consilii ingeniosi author erat de filo, per quod errores labyrinthi retexerentur.'

[28] In *Novum organum* Bacon uses the terms *subtilis* and *accuratus* (found in the epigraph) to describe the construction of clocks (*OFB*, vol. 11, 134). On the concept of subtlety see Rees G., "Atomism and 'Subtlety' in Francis Bacon's Philosophy", *Annals of Science* 37 (1980) 549–571.

[29] Bacon, *Instauratio magna*, in *OFB*, vol. 11, 19. 'Ædificium autem huius Vniuersi, structurâ suâ, intellectui humano contemplanti, instar labyrinthi est; vbi tot ambigua viarum, tàm fallaces rerum & signorum similitudines, tàm obliquæ & implexæ Naturarum spiræ & nodi, vndequaque se ostendunt.'

Fig. 1. Cristoforo Gherardi, *Dædalus forging the shield of Achilles*, 1555–1556, fresco, Palazzo Vecchio, Florence.

the thread of the labyrinth.'[30] Experiment is the clue to nature's inner workings and contrasts with the obscurity and darkness of nature *per se* which offers no clues to its hidden processes. The core of Baconian inquiry is experimental mechanics.[31]

Bacon's three types of mechanics are consistently correlated with distinct phases of inquiry. First, there is the mechanics of the artisan which is 'often merely empirical and operative.'[32] Second, there is *experientia literata* (literate experience) which proceeds by 'extending or transferring or putting together former inventions.'[33] Whereas the inventions of the mechanical arts 'come by chance,' those of *experientia literata* 'have been found by intentional experiment.'[34] The former way, in Bacon's terms, is but 'groping in the dark,' whereas the latter 'uses some direction and order in experimenting' so that the inquirer is, as it were, 'led by the hand.'[35] However, although 'not altogether operative,' *experientia literata* 'does not properly reach to philosophy.'[36] Third, there

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[30] Bacon, *Novum organum*, in *OFB*, vol. 11, 441.

[31] For an alternative reading see Pesic P., "Wrestling with Proteus: Francis Bacon and the 'Torture' of Nature", *Isis* 90, 1 (1999) 81–94; Idem, "The Clue to the Labyrinth: Francis Bacon and the Decryption of Nature", *Cryptologia* 24, 3 (2000) 193–211. I. Hacking dubs Bacon 'the first philosopher of experimental science,' in *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science* (Cambridge: 1983) 246. On Robert Boyle and experiment see Sargent R.-M., *The Diffident Naturalist: Robert Boyle and the Philosophy of Experiment* (Chicago: 1995). The best general collection on experiment to date is Gooding D. – Pinch T. – Schaffer S. (eds.), *The Uses of Experiment: Studies in the Natural Sciences* (Cambridge: 1989).

[32] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 365, cf. vol. 1, 572. 'sæpius mere empiricam et operariam.'

[33] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 366, cf. vol. 1, 572. 'per extensionem quandam vel translationem vel compositionem inventorum priorum deprehensa.'

[34] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 366, cf. vol. 1, 572.

[35] Bacon, *De augmentis scientiarumi*, in *SEH*, vol. 4, 413, cf. vol. 1, 623: 'cum quis *experimenta omnigena absque ulla serie aut methodo tenet*, ea demum mera est palpatio; cum vero *nonnulla utatur in experimentando directione et ordine*, perinde est ac si manu ducatur' (italics in original). It should be noted that although I use the term 'inquirer' to refer to a person following the Baconian way of inquiry, Bacon envisaged a hierarchy of inquirers with different skills and training. For the 'several employments and offices' of the fellows of Salomon's House, see *New Atlantis*, in *SEH*, vol. 3, 164–165. Artisans are excluded from Salomon's House but the fellows 'collect' their experiments. As Charles Whitney rightly says, 'the relationship the author of the *New Atlantis* would like to see is on a colonial model. The secrets of lower-class artisans, cheerful no doubt in their humble labors and modest rewards, may be exploited at will by a learned elite who find profit in those labors [...].' See Whitney C.C., "Merchants of Light: Science As Colonization in the *New Atlantis*", in Sessions W.A. (ed.), *Francis Bacon's Legacy of Texts: 'The Art of Discovery Grows with Discovery'* (New York: 1990) 255–268, on 265.

[36] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 366, cf. vol. 1, 572. 'quae nec prorsus operaria est, neque tamen philosophiam proprie attingit.'

is philosophical mechanics 'which is connected with physical causes.'[37] This proceeds by experiments 'worked out by the light of causes and axioms' and does belong to philosophy.[38] According to Bacon, this kind 'has been handled by Aristotle promiscuously, by Hero in spirituals, by Georgius Agricola [...] very diligently in minerals, and by many other writers in particular subjects.'[39] Philosophical mechanics is part of a higher phase of inquiry—'the Interpretation of Nature'—which Bacon describes as the source of 'the light itself.'[40] Because Bacon conceives of an elaborately phased process, no particular Baconian experiment may be understood without first grasping its schematic placement.

Although Rossi and Farrington clearly perceive the importance of Bacon's appropriation and inclusion of the mechanical arts, their historicised accounts obscure the complexity of Bacon's procedural requirements. In the interests of large-scale historical narratives, subsequent commentators have enhanced our understanding of the cultural emergence of experimentation but Bacon's detailed analysis has been overlooked in the process. Neither Rossi nor Farrington analysed the central Baconian concept of nature bound underpinning his appraisal of mechanics. Moreover, the significance of philosophical mechanics—which plays a fundamental role in effecting the union of the mind (*mens*) and things (*res*)—is entirely overlooked. The following account elaborates on Bacon's notion of experimental mechanics as a thread to guide the human intellect through nature's labyrinthine pathways.

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[37] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 366, cf. vol. 1, 572. 'quæ cum Causis Physicis conjuncta est.'

[38] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 366, cf. vol. 1, 572. 'per causarum et axiomatum lucem eruta sunt.'

[39] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 366, cf. vol. 1, 572. 'Enimvero Mechanicam, de qua nunc agimus, tractavit Aristoteles promiscue; Hero in Spiritalibus; etiam Georgius Agricola [...] diligenter admodum in Mineralibus; aliique quamplurimi in subjectis particularibus.'

[40] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 413, cf. vol. 1, 623. 'Nam *Lumen ipsum*, quod tertium fuit, ab Interpretatione Naturæ, sive Novo Organo, petendum est' (italics in original). 'Interpretation of Nature' is the name Bacon gives to the final phase of inquiry which ascends to axioms, then descends from axioms to new experiments. This phase of inquiry is described in *Novum organum* (whose full title is *Novum Organum or True Directions* concerning the Interpretation of Nature). Bacon uses this term because natural knowledge requires that we interpret the oracles of the senses. See Bacon, *Distributio operis*, in *OFB*, vol. 11, 35.

2. *Preliminary Background*

As Michel Malherbe rightly says, Baconian inquiry 'has a single purpose: to answer the question of invention.'[41] The complex relationship between invention and inquiry must be explicated against the background of major themes in Bacon's natural philosophy. Among the most significant of these are: Bacon's theory of matter and cosmogony;[42] the relationship between nature free and nature bound; the doctrine of forms; and the necessity of a union of things (*res*) and mind (*mens*). This paper argues that natural-philosophical themes explain the role of mechanics in Baconian inquiry. Before looking in detail at the role of mechanics in Bacon's programme, I shall therefore give a brief overview of central themes that constitute the natural-philosophical foundations of Baconian inquiry. As I deal with these themes elsewhere, the following is a bare summary of the principal doctrines.[43]

In the following passage from a piece entitled *Mr. Bacon in praise of knowledge* (1592) Bacon outlines the problem solved by inquiry:

> Are we the richer by one poor invention, by reason of all the learning that hath been these many hundred years? The industry of artificers maketh some small improvement of things invented; and chance sometimes in experimenting maketh us to stumble upon somewhat which is new; but all the disputation of the learned never brought us to light one effect of nature before unknown.

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[41] Malherbe M., "Bacon's Method of Science", in Peltonen M. (ed.), *The Cambridge Companion to Bacon* (Cambridge: 1996) 75–98, on 76.

[42] I am particularly indebted to Graham Rees's seminal work on Bacon's matter theory. See Rees G., "Francis Bacon's Semi-Paracelsian Cosmology", *Ambix* 22, 2 (1975), 81–101; Idem, "Francis Bacon's Semi-Paracelsian Cosmology and the *Great Instauration*", *Ambix* 22, 3 (1975) 161–173; Idem, "Matter Theory: A Unifying Factor in Bacon's Natural Philosophy", *Ambix* 24, 2 (1977) 110–125; Idem, "Atomism and 'Subtlety' in Francis Bacon's Philosophy" 549–571. See also Rees's detailed introduction and commentary in *The Oxford Francis Bacon*, especially vols 6 and 13; On Bacon's natural philosophy see Primack M., "Francis Bacon's Philosophy of Nature" (unpubl. Ph.D. diss., Johns Hopkins University, 1962); Idem, "Outline of a Reinterpretation of Francis Bacon's Philosophy", *Journal of the History of Philosophy* 5 (1967) 123–132. On the foundational role of matter theory in Bacon's cosmology see Gaukroger S., "The Role of Matter Theory in Baconian and Cartesian Cosmologies", *Perspectives on Science* 8, 3 (2000) 201–222. For an excellent overview of the controversies surrounding the question of Bacon's affiliation to traditional atomist views see Manzo S., "Francis Bacon and Atomism: A Reappraisal", in Lüthy C. – Murdoch J.E. – Newman W.R. (eds.), *Late Medieval and Early Modern Corpuscular Matter Theories* (Leiden: 2001) 209–243.

[43] Weeks S., "Francis Bacon's Science of Magic" (unpubl. Ph.D. diss., University of Leeds, 2007); Idem, "Francis Bacon and the Art-Nature Distinction", *Ambix* 54, 2 (2007) 117–145.

> [we need] the happy match between the mind of man and the nature of things [...] And what the posterity and issue of so honourable a match may be, it is not hard to consider. Printing, a gross invention; artillery, a thing that lay not far out of the way; the needle, a thing partly known before; what a change have these three made in the world in these times; the one in the state of learning, the other in the state of war, the third in the state of treasure, commodities, and navigation. And those, I say, were but stumbled upon and lighted upon by chance. Therefore, no doubt the sovereignty of man lieth hid in knowledge; wherein many things are reserved, which kings with their treasure cannot buy, nor with their force command; their spials and intelligencers can give no news of them, their seamen and discoverers cannot sail where they grow. Now we govern nature in opinions, but we are thrall unto her in necessity; but if we would be led by her in invention, we should command her in action.[44]

Bacon maintains that discoveries such as the compass and artillery were 'lighted upon by chance.' Unfortunately chance, although undoubtedly 'a useful originator of things, [...] scatters her blessings on mankind only after tedious and tortuous wanderings.'[45] However, these discoveries demonstrate matter's potential and suggest additional possibilities. Much is made of the discovery of gunpowder but, according to Bacon, artillery is the result of proximate and accidental discovery. In Bacon's terms, 'the rule is that what discoveries lie on the surface exert but little force. The roots of things, where strength resides, are buried deep.'[46] If things which lie on the surface have made such radical changes, how much greater, Bacon wonders, are the things which lie hidden deep in nature's recesses.

Access to matter's hidden virtues requires knowledge. Knowledge is gained via inquiry so that, in Malherbe's apt terms, we 'invent truth and produce works methodically, and not by chance.'[47] Chance may

[44] Bacon, *Mr. Bacon in Praise of Knowledge*, in *The Letters and Life of Francis Bacon* (hereafter abbreviated as *LL*) ed. by Spedding J., vols 8–14 (London, 1861–74) vol. 8, 123–126. This passage is cited in Farrington B., *Francis Bacon* 34–35; Rossi P., *Francis Bacon* 23. As Rees rightly says, *Mr. Bacon in Praise of Knowledge* is 'an essential document for our understanding of the earliest phases of Bacon's intellectual development,' "Atomism and 'Subtlety' in Francis Bacon's Philosophy" 553.

[45] Bacon, *Cogitata et visa*, in *BF*, 73, cf. *SEH*, vol. 3, 591. 'Casum, authorem rerum proculdubio utilem; sed qui per longas ambages et circuitus donaria sua in homines spargat.'

[46] Bacon, *Cogitata et visa*, in *BF*, 93, cf. *SEH*, vol. 3, 612. 'fere enim perpetuo fieri, ut quod inventu sit obvium, id opere sit infirmum; cum radices demum rerum virtute validæ, eædem situ abditæ sint.'

[47] Malherbe M., "Bacon's Method of Science" 76.

uncover things but knowledge abridges the 'long ways of experience.'[48] In *Novum organum*, having discussed artillery and the mariner's compass, Bacon writes:

> we should have every hope that nature's recesses still contain many secrets of excellent use which are quite unrelated to and unparalleled by anything already discovered, but stand well off the beaten track of fancy and are still undiscovered. These very things will also no doubt come to light some day after the lapse of long ages [...] but by the route of which I now speak they can be speedily, suddenly and simultaneously anticipated and made manifest.[49]

This route through the intricacies of nature is mapped out by the Baconian way of inquiry. It proceeds by increasingly unifying particulars until it arrives at knowledge of forms ('axioms of the highest generality').[50] It is crucial to be clear that in Bacon's view only knowledge of forms will uncover matter's possibilities and lead to magical works. Hence the opening aphorism of Book 2 of *Novum organum* states that the 'aim of human knowledge' is the discovery of forms, and the 'aim of human power' (magic) is the generation and superinduction of new natures 'on a given body'—in other words, 'metamorphosis.'[51] Baconian natural

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[48] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 361, cf. vol. 1, 567. 'ut experientiæ ambages et itinera longa [...] abbrevient.'

[49] Bacon, *Novum organum*, in *OFB*, vol. 11, 167–169. 'Itaquè sperandum omninò est, esse adhuc in Naturæ sinu, multa excellentis vsûs recondita, quæ nullam cum iam Inuentis cognationem habent, aut parallelismum; sed omninò sita sunt extra vias phantasiæ, quæ tamen adhuc inuenta non sunt; quæ proculdubiò per multos sæculorum circuitus & ambages, & ipsa quandoquè prodibunt [...] sed per viam quam nunc tractamus, properè, & subitò, & simul repræsentari, & anticipari possunt.'

[50] Bacon, *Novum organum*, in *OFB*, vol. 11, 71. A full discussion of Bacon's doctrine of forms lies outside the immediate purpose of this paper. However, it should be emphasised that a Baconian form is not a recipe. For Bacon, a form describes the limitation of nature's power which gives rise to a given simple nature, for example, heat. Crucially, Bacon's forms unify nature by identifying the common cause underlying all manifestations of a given simple nature. Bacon conceives of the axiomatic ascent as a pyramid which unifies knowledge. It inverts the primordial unfolding from unity to multiplicity. Through the experimental derivation of axioms, natural phenomena (*natura naturata*) are unified under increasingly more general axioms until the inquiry arrives at forms (*natura naturans*).

[51] Bacon, *Novum organum*, in *OFB*, vol. 11, 201. 'Svper datum Corpus nouam Naturam, siue nouas Naturas generare & superinducere, Opus & Intentio est humanæ Potentiæ. Datæ autem Naturæ Formam [...] inuenire, Opus & Intentio est humanæ Scientiæ.' In *Abecedarium nouum naturæ*, 'Sum ΓΓΓ' concerns magic: 'the transformation or metamorphosis of bodies [*versionis, siue metamorphoseos corporum*], a most powerful effect in nature and one by which human power is (as far as it is allowed) raised to the highest degree' (*OFB*, vol. 13, 209).

magic will, Bacon claims, manifest 'things that have never been done before,' and which 'human thought can barely grasp.'[52] In *De interpretatione naturæ sententiæ xii* he explains, 'such works are called *Epistemides*, that is, daughters of knowledge, which do not come into actuality otherwise than through knowledge and pure interpretation.'[53] All works (*opera*) produced without knowledge of forms are intermediaries (*media*) which the inquirer 'pursues foreseeing the end and recognising as intermediaries.'[54] The role of these intermediaries is discussed below. The discovery of forms requires the union of *res* and *mens* and the very possibility of this union is entailed by the principle of Baconian matter. The union cannot be established by contemplative or discursive means because it necessarily relies on the operative practice of engaging nature experimentally. Mechanics is the work of experiment and this is its essential contribution to inquiry. The following brief overview illustrates how natural philosophy coheres perfectly with Bacon's inquiry and how, on the basis of Baconian matter, true invention is possible. I shall begin with a summary of Bacon's cosmogony.

Bacon's cosmogony posits a single principle, an enriched and appetitive matter (*materia prima*). Baconian matter is eternal, unchanging, and the plenipotentiary source of all things. On this unique and self-sufficient cause all possible states are dependent. In his efforts to raise the ontological status of matter, Bacon designates the atom 'cause of causes' (*causa causarum*).[55] Accordingly, the atom is 'the supreme rule of act and power [*actus et potentiæ*], and the true moderator of hope and works.'[56] In the primordial chaos, matter hides within its 'fold' (*plica*) the

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[52] Bacon, *Novum organum*, in *OFB*, vol. 11, 203, 207.

[53] My trans., Bacon, *De interpretatione naturæ sententiæ xii*, in *SEH*, vol. 3, 788. 'Talia opera *Epistemides* vocantur, id est scientiæ filiæ, quæ non alias in actum veniunt quam per scientiam et interpretationem meram, cum nihil obvii contineant.' A translation of Bacon's *De interpretatione naturæ sententiæ xii* may be found in Weeks S., "Francis Bacon's Science of Magic" 305–325.

[54] My trans., Bacon, *De interpretatione naturæ sententiæ xii*, in *SEH*, vol. 3, 788. '[...] alia fine præviso et mediis cognitis exequitur.'

[55] Bacon, *De principiis atque originibus*, in *OFB*, vol. 6, 198; See also *De sapientia veterum*, in *SEH*, vol. 6, 655. Bacon often uses the word 'atom' synecdochically to refer to the principle itself, that is, to *materia prima*. It should be clear from the above discussion that the word 'atom' is not used by Bacon in the traditional Epicurean or Lucretian sense, or in the sense of later mechanical philosophers. On Bacon and atomism see Rees G., "Atomism and 'Subtlety' in Francis Bacon's Philosophy" 71. For a full discussion of Bacon's relationship to traditional atomism see Gemelli B., *Aspetti dell'atomismo classico nella filosofia di Francis Bacon e nel Seicento* (Florence: 1996).

[56] Bacon, *Cogitationes de natura rerum*, in *SEH*, vol. 5, 423, cf. vol. 3, 18. 'actus et potentiæ suprema regula, et spei et operum vera moderatrix.'

power to bring into being all potential worlds.[57] Through its generative capacity, matter's enfolded power is explicated in a process which Bacon calls the 'multiplication' (*multiplicatio*) of the power of the atom.[58] In its unfolding from a state of chaos to system, matter necessarily imposes a constraint on its absolute potency. This move, although a contraction in terms of potency, entails a concomitant outward expansion of generative power. From a state of homogeneous unformed unity, matter unfolds into a limited but organised multiplicity of forms. The multiple powers of matter, already inherent in the unformed chaos, are capable of self-organisation and self-restraint by virtue of its appetitive quality. Through the inherent unificatory power of matter an eventual stable system or sustainable world—what Bacon calls the 'great schematism'—is produced and a dynamic tension maintained throughout the whole.[59] This dynamic tension also pertains to individual bodies where stability is always a matter of the dominance of some motion (or motions) over others. Baconian matter not only accounts for cosmogonical beginnings but also provides the foundation for the ultimate goal of operative power: 'in the atom's body exist the elements of all bodies, and in the atom's motion and virtue exist the beginnings of all motions and virtues.'[60]

The primordial restraint on matter's absolute power leaves a potentially available resource. Therefore Bacon maintains,

> if any skilful Servant of Nature shall bring force to bear on matter, and shall vex it and drive it to extremities as if with the purpose of reducing it to nothing, then will matter (since annihilation or true destruction is not possible except by the omnipotence of God) finding itself in these straits, turn and transform itself into strange shapes.[61]

The powers of matter, Bacon insists, are not fully utilised in this world, leaving a remainder of endless possibilities. The current world

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[57] Bacon, *Historia densi & rari*, in *OFB*, vol. 13, 163.

[58] Bacon, *De principiis atque originibus*, in *OFB*, vol. 6, 201; See also *De sapientia veterum*, in *SEH*, vol. 6, 655.

[59] Bacon, *De principiis atque originibus*, in *OFB*, vol. 6, 251.

[60] Bacon, *De principiis atque originibus*, in *OFB*, vol. 6, 203. 'in corpore Atomi elementa omnium corporum, & in motu et virtute Atomi initia omnium motuum & virtutum insunt.'

[61] Bacon, *De sapientia veterum*, in *SEH*, vol. 6, 726, cf. 652. 'si quis peritus Naturæ Minister vim adhibeat materiæ, et materiam vexet atque urgeat, tanquam hoc ipso destinato et proposito, ut illam in nihilum redigat; illa contra (cum annihilatio aut interitus verus nisi per Dei omnipotentiam fieri non possit), in tali necessitate posita, in miras rerum transformationes et effigies se vertit.'

is merely one termination of the unfolding of matter, haphazardly arrived at and sustained by habit. This is nature 'free' (*libera*), Bacon says, unfolding herself in 'her ordinary course of development [*cursu consueto se explicans*]; as in the heavens, in the animal and vegetable creation, and in the general array of the universe.'[62] There is no fixity of species in Bacon's natural philosophy, therefore existing bonds can be broken and new patterns formed through art. This suggestion of unlimited possibilities illustrates Bacon's radical transformation of the concept of nature. In an equally radical transformation, he redefines the concept of human operative power. Nature's ordinary course (the current world) represents only a single facet of the possible facets which nature could potentially present. This leads to the striking tenet that forms the cornerstone of Bacon's programme, namely, that the artful manipulation of bodies involves a recapitulation of matter's primordial self-binding or self-imposed limitations on its absolute power. For Bacon, art is the operative analogue of the primary cosmogonical contraction of matter's absolute potency. In Bacon's programme, art intervenes in matter's habitual motions, shifting the current system out of its ordinary course in order to actualise hidden facets of nature. The eternity of matter implies neither further creation nor destruction of its original quantum. It is a fundamental principle of Bacon's vision that matter (in order to preserve this quantum) will make further use of its hidden powers when vexed or 'bound' (*constricta*).[63]

Without the central Baconian concept of nature bound, as a complement to nature free, Baconian reform has neither philosophical nor operative foundations. This concept underpins the following passage:

> Natural is [...] set against artificial; these are potentialities for being but by a particular efficient, namely by nature itself or by the hand of man. For it is not possible for a great number of artificial bodies to exist except by the hand of man.[64]

[62] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 294, cf. vol. 1, 496. 'Aut enim libera est natura et cursu consueto se explicans, ut in cœlis, animalibus, plantis, et universo naturæ apparatu.'

[63] My trans., Bacon, *Descriptio globi intellectualis*, in *OFB*, vol. 6, 98.

[64] My trans., Bacon, *Abecedarium nouum naturæ*, in *OFB*, vol. 13, 218. 'Naturale [...] opponitur artificiali. Hæc sunt potentialia ad ens, sed per tale efficiens, videlicet per naturam ipsam, aut per manum hominis. Non enim possibile est vt pleraque artificialium existant nisi per manum hominis.'

For Bacon, artificial bodies are simply bodies produced by nature bound, that is, nature constrained and deviated from its routine behaviour. This operative relationship between nature free and nature bound is the key to understanding Bacon's role for mechanics. In programmatic terms, the arts exhibit the possibility of an 'alternative universe [...] of things.'[65] But in inquisitional terms, mechanics coheres with Bacon's natural-philosophical principles. Mechanics functions at all phases of inquiry until we arrive at the point where 'unparalleled' works can be systematically produced.[66] At this point, mechanics (Bacon thinks) will be transformed into 'true natural magic.'[67] The power to produce novelties (what Bacon describes as the *magnalia naturæ*) is ultimately the power to superinduce new natures, which requires knowledge of forms. But knowledge of forms is impossible without experimental intervention where each discovery is a stepping-stone to further discovery until we arrive at primary axioms (forms). Consequently, Baconian inquiry produces knowledge through an engagement with matter intended for the discovery of forms. In this way the human mind is taken by an indirect route into the heart of matter's hidden processes, culminating in the union of the mind (*mens*) and things (*res*).

The union of the mind (*mens*) and things (*res*) is a necessary condition of inquiry. The word *res* (in Bacon's texts) when it is coupled with *mens* invariably refers to matter and its properties.[68] The desired union of the mind with things is frustrated through self-imposed obstacles and through the inherent impenetrability and subtlety of nature. Both these impediments are entrenched in current learning because in responding to the resulting epistemological impasse, the mind resorts to imaginative explanations and unfounded theorising. Book 1 of *Novum organum* concentrates on the reasons for declination into error. It proposes a therapeutic regeneration of the mind (through a reduction to a primi-

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[65] Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 455.

[66] See Bacon, *Novum organum*, in *OFB*, vol. 11, 167–169.

[67] Bacon, *Advancement of learning*, in *OFB*, vol. 4, 90. Bacon's definition of magical works as 'unparalleled' works is central to his programme. No other phase of Baconian inquiry produces 'unparalleled' works.

[68] Unfortunately, the technical meaning of this couple (which occurs in the opening aphorism of *Novum organum*) has been obscured in translations. For instances of the *res-mens* pairing see Bacon, *Instauratio magna*, in *OFB*, vol. 11, 2, 6; *Distributio operis*, in *OFB*, vol. 11, 36; *Novum organum*, in *OFB*, vol. 11, 64, 442; *De principiis atque originibus*, in *OFB*, vol. 6, 208. For alternative views on the meaning of these terms see Kitchin G.W., *Novum organum: sive indicia vera de interpretatione naturæ* (Oxford: 1855) 8, n. 3; Fowler T. (ed.), *Bacon's Novum Organum*, second edition (Oxford: 1889) 191–192; Farrington B., *BF*, 51, n. 1; Rees G., *OFB*, vol. 11, 501–502.

tive ignorance) to prepare it for union with things (*res*). Book 2 outlines the inquisitional procedures designed to lead the mind through nature's subtleties. Bacon is adamantly opposed to any suggestion that knowledge can be obtained through Platonic contemplation or discursive reasoning. Experiment, according to Bacon, is the thread which guides inquiry and gradually leads the mind to 'the very innards [*visceribus*] of nature.'[69] Experiment keeps inquiry immersed in matter, preventing the withdrawal of 'thoughts too soon and too far from experience and particulars.'[70] Thus although Baconian inquiry has an operative goal, this requires the union of *res* and *mens*.[71] As Bacon puts it, 'from this union there [will] spring helps for men and a line of discoveries [*stirps Inuentorum*] which may to some degree subdue and mitigate their needs and miseries.'[72] Inquiry begins with the senses which, although weak and insufficient, are nonetheless the first point of contact with matter. Notwithstanding that the aim of knowledge is to discover forms, the mind *en route* must be subjected to a humiliating descent from the heights of imaginative excess to immersion in the commonplace. The following sections analyse why Bacon accorded inquisitional pre-eminence to the various kinds of mechanics.

3. *Mechanical History*

Baconian inquiry begins with the collection of 'a natural and experimental history [...] for the building up of philosophy.'[73] Bacon refers

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[69] Bacon, *Distributio operis*, in *OFB*, vol. 11, 33.

[70] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 361, cf. vol. 1, 566. 'Radix autem mali hujus, ut et omnium, ea est; quod homines et propere nimis, et nimis longe, ab experientia et rebus particularibus cogitationes suas divellere et abstrahere consueverunt, et suis meditationibus et argumentationibus se totos dedere.'

[71] This explains the prominence of the *res*-*mens* union in the opening sentences of Bacon's *Instauratio magna* (*OFB*, vol. 11, 2, 6) and *Novum organum* (*OFB*, vol. 11, 64, aphorism 1).

[72] Bacon, *Distributio operis*, in *OFB*, vol. 11, 37. 'vt ex eo connubio auxilia humana, & stirps Inuentorum, quæ necessitates ac miserias hominum aliquâ ex parte doment & subigant, suscipiatur.'

[73] Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 451. 'Historiæ Naturalis & Experimentalis, eius generis, quæ sit in Ordine ad Condendam Philosophiam.' In *Advancement of learning* Bacon refers to 'mindes emptie & vnfraught with matter, & which haue not gathered that which *Cicero* calleth *Sylua* and *Supellex*, stuffe and varietie' (*OFB*, vol. 4, 59, italics in original). See Cicero, *Orator*, iii, 12; xxiv, 80. Bacon also refers to the primary history as the '*Mother History*' because its purpose is 'to illuminate the discovery

to this as the primary history because it is 'the primary matter [*Materia Prima*] of philosophy, and the basic stuff and raw material [*Supellex, siue Sylua*] of true induction.'[74] Successful inquiry, however, depends upon collecting the right kind of natural history. A philosophically useful natural history must include the mechanical arts:

> For the *raison d'être* of a natural history drawn up for its own sake is one thing, but one compiled systematically to inform the intellect for the building up of philosophy is quite another. And these two kinds of history differ in many respects but above all in this: that the first takes in the variety of natural species but not the experiments of the mechanical arts.[75]

When compiling the primary history, 'the end governs the means.'[76] 'The end' here refers to the philosophical task of 'constructing true axioms,' and in this way the natural and experimental history serves natural philosophy.[77] Bacon's natural philosophy propounds a threefold division of nature. Nature 'is either free and unfolds itself in its ordinary course; or it is torn from its course by the crookedness and arrogance of matter and by the violence of impediments; or it is restrained and moulded by art and human agency.'[78] This division is reflected in the primary history: it must accordingly deal with 'the *liberty* of nature, or its *errors* or its *bonds*.'[79] To reflect the threefold division of nature, Bacon divides the primary history into '*History* of *Generations*, of *Pretergenerations* and of *Arts*, the last of which,' he says, 'I have also got used to calling *Mechanical* and *Experimental*.'[80] Moreover, he prioritises the history

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of causes and nourish philosophy with its mother's milk' (*Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 453, italics in original; *Distributio operis*, in *OFB*, vol. 11, 39).

[74] Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 455. 'tanquàm Materia Prima Philosophiæ, atque veræ Inductionis Supellex, siue Sylua.'

[75] Bacon, *Novum organum*, in *OFB*, vol. 11, 157. 'Alia enim est ratio Naturalis Historiæ, quæ propter se confecta est; alia eius, quæ collecta est ad informandum Intellectum in ordine ad condendam Philosophiam. Atque hæ duæ Historiæ tùm alijs rebus, tùm præcipuè in hoc differunt: quòd prima ex illis specierum naturalium varietatem, non Artium Mechanicarum Experimenta contineat.'

[76] Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 457.

[77] Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 457.

[78] Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 455. 'Natura in triplici Statu ponitur, & tanquam Regimen subit trinum. Aut enim libera est, & cursu suo ordinario se explicat; aut à prauitatibus & insolentijs Materiæ, atque ab Impedimentorum violentiâ de statu suo detruditur; aut ab Arte & ministerio humano constringitur & fingitur.'

[79] Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 455. 'Tractat enim aut Naturæ *Libertatem*, aut *Errores*, aut *Vincula*' (italics in original).

[80] Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 455. 'vt non malè Eam partiri possimus, in *Historiam Generationum, Prætergenerationum*, & *Artium*; quarum postremam etiam *Mechanicam* & *Experimentalem* appellare consueuimus' (italics in original). On Bacon's

of the mechanical arts over and above the history of generations and pretergenerations (marvels). 'The use of History Mechanical is,' he says, 'of all others, the most radical and fundamental towards natural philosophy.'[81]

In spite of Bacon's clear statement of an inquisitional role for the mechanical arts, the received view portrays his reappraisal in terms of a shift in early-modern cultural attitudes towards artisans and the operative arts.[82] According to Rossi, Bacon 'strove to rehabilitate the mechanical arts.'[83] Similarly, Farrington argues that 'the mechanical arts were to be rescued [by Bacon] from their traditional contempt and restored to a central position in the history of civilisation.'[84] However, far from praising the inventions of the mechanical arts, Bacon states that we should 'shed tears for the human condition instead, seeing that in so many ages poverty and barrenness of facts and discoveries has been so great.'[85] In *Filum labyrinthi* he observes: 'when men did set before themselves the variety and perfection of works produced by mechanical arts, they are apt rather to admire the provisions of man, than to apprehend his wants.'[86] However, he warns that this 'conceit of plenty is one of the principal causes of want.'[87] The received view is confronted with the problem of reconciling Bacon's negative assessment of the productive power of the arts with his necessary inclusion of them in the primary history.

The above problem can be resolved by investigating Bacon's *inquisitional* role for the mechanical arts. Bacon's negative assessment of the arts is directed at an over-estimation of their achievements and limited goals—their traditional ends. But his positive appraisal is directed at

innovations in natural history see Findlen P., "Francis Bacon and the Reform of Natural History in the Seventeenth Century", in Kelley D.R. (ed.), *History and the Disciplines: The Reclassification of Knowledge in Early Modern Europe* (Rochester: 1997) 239–260.

[81] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 297, cf. vol. 1, 500. 'Historiæ Mechanicæ usum erga philosophiam naturalem esse maxime radicalem et fundamentalem.'

[82] For a recent discussion on the input of artisanal skills to natural philosophy see Smith P., *The Body of the Artisan*, especially 237–241; on the transformation of skill into the more theoretical and systematic phenomenon of expertise in which Bacon is said to play a fundamental role see Ash E.H., *Power, Knowledge, and Expertise* 186–212.

[83] Rossi P., *Francis Bacon* 9.

[84] Farrington B., *BF*, 32.

[85] Bacon, *Novum organum*, in *OFB*, vol. 11, 135. '& potiùs humanæ conditionis miserebitur, quòd per tot sæcula, tanta fuerit rerum & Inuentorum penuria, & sterilitas.'

[86] Bacon, *Filum labyrinthi*, in *SEH*, vol. 3, 497. See also *Novum organum*, in *OFB*, vol. 11, 135.

[87] Bacon, *De sapientia veterum*, in *SEH*, vol. 6, 749, cf. 672. 'denique opinionem copiæ inter maximas causas inopiæ reponi.'

their operative means. The philosophical potential of the mechanical arts is obtained from their operative means, not their productive ends: even without the slightest knowledge of causes, the arts have always been productive. Bacon, as outlined in the Introduction, posits three distinct types of mechanics each correlated with a distinct phase of inquiry. The successes of the mechanical arts are almost entirely due to chance and the result of immediate needs. In Bacon's negative perception, the inventions of the mechanical arts are mere contingencies, discovered opportunistically. The mechanical arts exploit few of the possibilities hidden in material bodies: 'the original inventions and conclusions of nature which are the life of all that variety, are not many nor deeply fetched.'[88] The predominance of chance discovery serves to distinguish the mechanical arts from the more systematic inquiry characteristic of philosophical mechanics which depends on knowledge of physical causes.

In *Cogitata et visa* Bacon writes, 'the mechanical arts draw little light from philosophy, though they do gradually enlarge the humble web woven by experience.'[89] Artisans lack knowledge of causes; their mechanics is 'merely empirical and operative.'[90] However, even at the lowest level of operative engagement with nature, experimentation takes place. Bacon's positive perception of the mechanical arts relates principally to the fact that they are 'founded on nature and the light of experience.'[91] Crucially, and in contrast with the discursively oriented scholastic sciences, the mechanical arts have 'stayed attached to nature's womb and been fed by it.'[92] This attachment to nature is an essential property of Baconian experimentation and the necessary condition for all inquiry. Without the mind's immersion in nature, no amount of organisation, royal funding, cooperation, rhetoric, propagandising etc. will achieve the aim of knowledge—the discovery of forms. Bacon's extraordinary insight into the conditions of inquiry allowed him to

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[88] Bacon, *Filum labyrinthi*, in *SEH*, vol. 3, 497. See also *Novum organum*, in *OFB*, vol. 11, 135.

[89] Bacon, *Cogitata et visa*, in *BF*, 73, cf. *SEH*, vol. 3, 591. 'Mechanicas artes non multum lucis a philosophia petere, sed experientiæ telas, lentas sane ac humiles, paulatim continuare.'

[90] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 365, cf. vol. 1, 572. 'mere empiricam et operariam.'

[91] Bacon, *Novum organum*, in *OFB*, vol. 11, 119. 'in Naturâ & Experientiæ luce fundatæ sunt.'

[92] Bacon, *Novum organum*, in *OFB*, vol. 11, 119. 'vtero Naturæ adhærerent, atque ab eâdem alerentur.'

recognise experimentation as the source of discovery in the mechanical arts. The operative arts are a necessary condition for the discovery of causes. Commentators typically insist that Bacon's elevation of the mechanical arts is a consequence of their productive power in comparison with barren scholastic disputation. However, Bacon elevates not the artisan and his products but experimentation as the *sine qua non* of inquiry. As he says, he 'care[s] little for the mechanical arts in themselves, except insofar as they help in fitting out philosophy.'[93] In the absence of experimentation there is neither the possibility of negotiating nature's bewildering labyrinth, nor systematic discovery.

To achieve his philosophical goal, Bacon converts practices formerly concerned with ends (the utility and productive power of the arts) into inquisitional means, thereby transforming the mechanical arts into a tool of inquiry. Bacon's innovation is to abstract mechanical practices from their limited goals so that *usus* becomes a factor in philosophical inquiry.[94] Because Bacon perceives that the arts illuminate causes, he distinguishes between *experimenta fructifera* (fruit-bearing experiments) and *experimenta lucifera* (light-bearing experiments).[95] Whereas the former are 'experiments of Use,' the latter are 'experiments of no use in themselves but which only contribute to the discovery of causes.'[96] *Experimenta lucifera* contribute nothing to the art in question. For example, 'the fact that mud-coloured lobsters and crabs turn red when cooked means nothing

[93] Bacon, *Catalogus historiarum particularium*, in *OFB*, vol. 11, 485. 'Parùm enim nobis curæ est de Artibus ipsis Mechanicis, sed tantùm de ijs quæ afferunt ad instruendam Philosophiam.'

[94] For an excellent discussion of the complexities regarding the manner in which '*usus* may become theory' see Summers D., *The Judgment of Sense: Renaissance Naturalism and the Rise of Aesthetics* (Cambridge: 1987) 255–257. See also Desroches D., *Francis Bacon and the Limits of Scientific Knowledge* (London: 2006) especially 103–108.

[95] See, for example, Bacon, *Novum organum*, in *OFB*, vol. 11, 113, 157–159, 181.

[96] William Rawley (letter prefaced to *Sylva sylvarum*) *SEH*, vol. 2, 336; Bacon, *Sylva sylvarum*, in *SEH*, vol. 2, 501; *Novum organum*, in *OFB*, vol. 11, 157–159. 'Experimenta, quæ in se nullius sunt vsûs, sed ad inuentionem causarum & Axiomatum tantùm faciunt.' Boyle rightly points out that Bacon is not saying that *experimenta fructifera* are useless: 'For though that famous Distinction, introduc'd by the Lord *Verulam*, whereby Experiments are sorted into *Luciferous* and *Fructiferous*, may be (if rightly understood) of commendable Use; yet it would much mislead those that should so understand it, as if Fructiferous Experiments did so meerly advantage our interests, as not to promote our Knowledg.' However, Boyle wrongly argues that Bacon does not mean that 'the Experiments called Luciferous, did so barely enrich our Understandings, as to be no other waies useful.' This is a misinterpretation of Bacon who is quite clear that *experimenta lucifera* are 'of no use in themselves.' See Robert Boyle, *The Usefulness of Experimental Natural Philosophy*, II,2 (1671), in *The Works of Robert Boyle*, ed. by M. Hunter – E.B. Davis, 14 vols (London: 1999) vol. 6, 433.

to the diner, but this very instance is still very useful for inquiring into the nature of redness [. . .].'[97] I elaborate on the distinction between *experimenta fructifera* and *experimenta lucifera* in Part 4 where I examine Bacon's second type of mechanics, *experientia literata*. But it is important to note that although the latter are not typically useful (the end result may be perceived as failure in terms of *usus*), they are experiments which 'contribute and help most for informing the intellect.'[98] It is on the basis of their light-producing capacity that the mechanical arts further the discovery of causes.

In *Parasceve ad historiam naturalem* Bacon adds that the history of arts also 'leads more directly to practice' (*magis rectà ducat ad Praxin*).[99] All phases of Baconian inquiry, from the primary history to magic, have a practical/experimental aspect. Baconian inquiry therefore requires practical knowledge (praxis) of the possible modes of experimentation or interfacing with nature. In *Novum organum* (Book 2, aphorism fifty), Bacon details the seven most general modes of 'human working on natural bodies.'[100] He adds that those modes of experimentation 'which are now known and have come into use' are the product of 'individual arts.'[101] Artisans of course deal with 'actual instruments and artful contrivances.'[102] The distinction between the mechanical arts and higher phases of the programme (philosophical mechanics and magic) does not concern praxis. The distinction relates only to the presence or absence of axiomatic knowledge; all phases deploy modes of experimentation. Magic—'*the Deduction of Forms to Works*' (*Deductio Formarum ad Opera*)—is praxis operating systematically on the basis of knowledge of forms.[103] Bacon does not think knowledge of forms is sufficient for superinducing new natures; one must also know the practical 'means [*Modos*] of

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[97] Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 463. 'Exempli gratiâ, quòd Locustæ, aut Cancri cocti, cùm priùs Colorem luti referrent, rubescant, nihil ad mensam: sed hæc ipsa Instantia tamen non mala est ad Inquirendam Naturam Rubedinis.' In *Commentarius solutus* Bacon notes that mechanical history should inquire 'all things collaterall incid*en*t or interuenient' (*LL*, vol. 11, 66, cited in *OFB*, vol. 4, 264).

[98] Bacon, *Novum organum*, in *OFB*, vol. 11, 157.

[99] Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 463. As R. Harré points out, *deducere* would 'in this period, have been understood in the physical sense of "leads out" or "produces" rather than the logical sense of "implies" or "entails,"' see "A Note on Ms. Horton's Defence of Bacon", *Studies in History and Philosophy of Science* 5, 3 (1974) 305–306, on 306.

[100] Bacon, *Novum organum*, in *OFB*, vol. 11, 419.

[101] Bacon, *Novum organum*, in *OFB*, vol. 11, 419.

[102] Bacon, *Novum organum*, in *OFB*, vol. 11, 419.

[103] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 5, 121, cf. vol. 1, 838 (italics in original).

superinducing.'[104] In *Advancement of learning* he says, 'he that knoweth well the Natures of *Waight, of Colour, of Pliant*, and *fragile* in respect of the hammer, of *volatile* and *fixed* in respect of the fire, and the rest, may superinduce vpon some Mettall the Nature, and forme of Gold by such *Mechanique* as longeth to the production of the Naturs afore rehearsed.'[105] According to Bacon, this will involve much 'sagacious endeavour.'[106] The mechanical arts therefore play a vital role in '*Bringing things down to Practice*' (de *Deductione ad Praxin*), which was to have been the subject of Book 7 of *Novum organum*.[107] Bacon's mechanical history would inquire (for each individual art), 'the Instrum*en*ts and Engins requesite—then the vse and adopitatio*n* [*sic*] of euery Instrum*en*t; then the woork it self and all the processe thereof w*i*th the tymes and seasons of doing euery part thereof.'[108] Regardless of the level of inquiry, the practicalities of experimentation are derived in the first instance from the mechanical arts. The turn to praxis as a necessary condition of operation at every level explains this particular contribution of the mechanical arts.

Having clarified the apparent ambiguity in Bacon's attitude towards the mechanical arts, it is now possible to elaborate on how they function as inquisitional means. Thus far I have alluded to two functions: the mechanical arts illuminate causes and they lead to practice (praxis). The light-bearing capacity of the mechanical arts is a consequence of the Baconian doctrine of the unity of nature, and the correlative doctrine of analogy.[109] The principle of unity entails the universal commonality of a limited set of causes (forms). This unity necessarily

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[104] Bacon, *Novum organum*, in *OFB*, vol. 11, 207. A Baconian form is not a recipe; it is an axiom of such generality that it is *not* restricted 'to certain means and certain specific modes of operating' (*Novum organum*, in *OFB*, vol. 11, 205). Hence magic requires 'the Deduction of Forms to Works.' For an alternative interpretation see Pérez-Ramos A., *Francis Bacon's Idea of Science* 109.

[105] Bacon, *Advancement of learning*, in *OFB*, vol. 4, 89 (italics in original).

[106] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 368, cf. vol. 1, 574: 'posse aurum multa et sagaci molitione tandem produci.'

[107] Bacon, *Novum organum*, in *OFB*, vol. 11, 273 (italics in original). *Novum organum* is an unfinished work: Bacon completed only two of nine intended books. See Rees G., *OFB*, vol. 11, xciv.

[108] Bacon, *Commentarius solutus*, in *LL*, vol. 11, 65–66, cited in *OFB*, vol. 4, 264. For the list of individual arts see *Catalogus historiarum particularium*, in *OFB*, vol. 11, 481–485. See also the large variety of 'Preparations and Instruments' described in *New Atlantis*, in *SEH*, vol. 3, 156–164.

[109] For an alternative treatment of Bacon's use of analogy see Park K., "Bacon's 'Enchanted Glass'", *Isis* 75, 2 (1984) 290–302. On the unity of nature see McRae R.F., "The Unity of the Sciences: Bacon, Descartes, Leibniz", *Journal of the History of Ideas* 18, 1 (1957) 27–48; Idem, *The Problem of the Unity of the Sciences: Bacon to Kant* (Toronto:

includes artificial processes: regardless of the source of motive power, the same formal causes (forms) are at work in natural and artificial operations. This should not be confused with the explanation that natural philosophy benefits from the arts in terms of the capacity of machines to model natural processes. In Rossi's account, 'the product of art, the machine, serves as a model for the conception and understanding of nature.'[110] His inclusion of Bacon's position with the later views of Descartes and Robert Boyle suggests that Bacon upholds a proto-mechanical philosophy of nature. However, although Descartes consistently characterises the universe as a machine, Bacon nowhere treats nature in mechanical terms.[111] Whilst it is correct that the same material and efficient causes operate across all domains, Baconian matter and its hidden motions cannot be explicated in terms of the configuration of particles in motion. Without this latter conception the mechanical analogy breaks down: nature for Bacon is not 'a great piece of clockwork.'[112] Bacon is adamant that material analogies are not 'onely similitudes.'[113] Baconian analogy describes an ontological property of things: 'the same footesteppes of Nature, treading or printing vppon seuerall subiects or Matters.'[114] According to Bacon, 'That kind of truth which comes from scientific analogy is very different from that which is enunciated on the basis of a portion of an idol.'[115] In inquisitional terms, the doctrine of analogy means that processes apparently separate and *prima facie* entirely independent are analogously united by the innate faculty of judgement. Knowledge of forms depends on the detection of analogous instances that cut across the whole range of matter's

1961). In *Novum organum* Bacon describes 'nature's union' as 'the most important thing of all' (*OFB*, vol. 11, 257).

[110] Rossi P., *Philosophy, Technology, and the Arts* 140.

[111] In the light of recent work on early modern matter theory, it is no longer possible to represent uniformly the supporters of the mechanical philosophy as holding a simplistic mechanical model of material processes. See for example, Henry J., "Occult Qualities and the Experimental Philosophy: Active Principles in Pre-Newtonian Matter Theory", *History of Science* 24 (1986) 335–381. For an excellent overview see Lüthy C. – Murdoch J.E. – and Newman W.R. (eds.), *Late Medieval and Early Modern Corpuscular Matter Theories* (Leiden: 2001).

[112] Robert Boyle as quoted in Rossi P., *Philosophy, Technology, and the Arts* 141.

[113] Bacon, *Advancement of learning*, in *OFB*, vol. 4, 78. See also *De augmentis scientiarum*, in *SEH*, vol. 4, 339, cf. vol. 1, 543.

[114] Bacon, *Advancement of learning*, in *OFB*, vol. 4, 78.

[115] My trans., Bacon, *Temporis partus masculus*, in *SEH*, vol. 3, 538. 'Longe alia est ratio [...] veritatis quæ est ex scientiæ analogia, alia quæ ex idoli sectione enuntiatur.'

manifestations. Bacon repeatedly argues for a widening of inquiry to incorporate as many analogous instances as possible:

> If men could only bring themselves not to fix their thoughts too intently on the consideration of the subject before them, rejecting everything else as irrelevant [*parerga*] […] [then] by a free passage and transference of their thoughts they would find many things at a distance which near at hand are concealed. And therefore, in the law of nature, as well as in the civil law, we must proceed with sagacity of mind to look for like and analogous cases [*ad similia et conformia*].[116]

The doctrine of analogy means that 'the same nature is latent in some things, but manifest and as it were palpable in others.'[117] Hence no simple nature can be found 'by examining the nature of a particular thing in isolation.'[118] Bacon insists that without extensive surveys across the full range of disparate phenomena there is a tendency to conform nature to the judgement rather than the judgement to nature. According to Bacon, 'this habit of *taking in just a few things* and *making assertions on the basis of them* has ruined everything.'[119] Instead, 'the intellect should be stretched and opened up to take in the image of the world as we really find it.'[120]

The unity of nature has consequences for Bacon's primary history because the judgement can detect analogies between natural and artificial motions. Bacon's *Historia ventorum*, for example, investigates the motion of the winds in machines such as windmills and the imitations of winds 'in machines made by man, as guns, mines, and powder

[116] Bacon, *Historia ventorum*, in *SEH*, vol. 5, 194–195, cf. vol. 2, 73: 'Si animum homines inducere possent, ut contemplationes suas in subjecto sibi proposito non nimium figerent, et cætera tanquam *parerga* rejicerent; nec circa ipsum subjectum in infinitum et plerunque inutiliter subtilizarent; haudquaquam talis, qualis solet, occuparet ipsos stupor, sed transferendo cogitationes suas et discurrendo, plurima invenirent in longinquo quæ prope latent. Itaque ut in Jure Civili, ita in Jure Naturæ, procedendum animo sagaci ad similia et conformia' (italics in original). *Parerga* is a term meaning 'incidentals'—it is used to describe deeds that were not one of the twelve great labours of Hercules but were incidental to the actual labour.

[117] My trans., Bacon, *Cogitata et visa*, in *SEH*, vol. 3, 609: 'Eandem enim naturam in aliis latentem, in aliis manifestam et quasi palpabilem esse.'

[118] My trans., Bacon, *Cogitata et visa*, in *SEH*, vol. 3, 609. 'Insciam enim et imperitam valde cogitationem esse, alicujus rei naturam in seipsa perscrutandi.' This is why Bacon criticises Gilbert for putting all his 'efforts into unearthing one particular experiment […] with the loadstone.' (*Novum organum*, in *OFB*, vol. 11, 111).

[119] Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 459. 'Istud enim, *Respicere pauca*, & *pronunciare secundùm pauca*, omnia perdidit' (italics in original).

[120] Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 459. 'sed expandendus Intellectus, & laxandus, ad Mundi Imaginem recipiendam, qualis inuenitur.'

magazines.'[121] The crucial point is that mechanical contrivances disclose matter's hidden motions. *Historia ventorum* demonstrates how analogy holds not just across diverse natural powers but also across the natural and the artificial. However, the artificial does not present the mind with a model of natural processes: a bellows is not a model of meteorological phenomena. The doctrine of analogy means that in artificially generated motions the inaccessible is brought within the mind's reach. The doctrine of analogy and the unity of nature (corollaries of Bacon's theory of matter) explain how the hidden motions of nature free may be analogously 'manifest and palpable' in the mechanical arts.

Art presents the mind with accessible processes. It makes the hidden virtues of matter palpable by bringing to the surface those motions necessary to specific operations. Art does not utilise all matter's powers at the same time: in artificial processes complex modes of nature's transmutations are of necessity analysed into simpler patterns. The mechanical arts routinely segregate and distinguish matter's capacities. In this process of separating out matter's complex motions, mechanical operations engage the judgement in distinctive virtues of matter at a local level. In contrast, when nature is free, complex nodes of motions are obscured under the bewildering array of phenomenal effects. For example (to use Robert Ellis's vivid image), when nature 'superinduces yellowness on the green leaf, or silently and gradually transforms ice into crystal,' we have no idea how these changes are brought about.[122] Whereas in the mechanical arts 'the manner of making and working' artefacts 'is generally plain to see,' in nature free 'it is often much less obvious.'[123] Confronted with nature's fecund and bewildering display, the mind is confused and powerless to identify specific causes for specific effects. By contrast, in its operative engagement with matter, the mind is brought into contact with 'things in motion' (*res in motu*):

> the most useful is the *History of Arts* because it displays things in motion and leads more directly to practice. Moreover it strips the mask and veil from natural things which generally lie concealed or hidden beneath a variety of shapes and outward appearances. In short, the vexations of

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[121] Bacon, *Historia ventorum*, in *SEH*, vol. 5, 195, cf. vol. 2, 74. See also *Historia ventorum*, in *SEH* vol. 5, 144–145, 185–187, 194–195, cf. vol. 2, 24–25, 64–65, 73–74.

[122] Ellis R.L., in *SEH*, vol. 1, 59.

[123] Bacon, *Novum organum*, in *OFB*, vol. 11, 301: 'quia Modus efficiendi & operandi huiusmodi Miracula Artis, manifestus vt plurimùm est; cùm plerunque in Miraculis Naturæ sit magis obscurus.'

> art are indeed like the chains and manacles of *Proteus* which betray the ultimate strivings and exertions of matter.[124]

Regardless of the level of causal understanding, experiments perforce constrain matter's habitual behaviour shifting nature from its routine tendencies. By this act of deviation the powers of matter manifest motions that are then directed to specific ends. Under vexation, matter openly displays otherwise hidden and secret motions, thus immediately extending the power of judgement, and focusing the mind on phenomena otherwise obscured in the complexities of nature free:

> For just as in affairs of state we see a man's mettle and the secret sense of his soul and affections better when he is under pressure than at other times, so nature's secrets betray themselves more through the vexations of art than they do in their usual course.[125]

The difference between the occasional deviations of nature (marvels) and the regular and daily deviations of the arts is that nature's assays are opaque, without detectable purpose, impenetrable to the naked understanding and beyond the capacity of the senses. The senses *per se* are prevented from seeing beyond surface phenomena: any judgement regarding causes is impossible without further inquiry, that is, without experiment. As Bacon puts it, we 'set little store by the immediate and peculiar perception of the sense, but carry the matter to the point where the sense judges only the experiment whereas the experiment judges the thing.'[126] It is through experimental deviation that selected powers of matter surface.

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[124] Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 463: 'maximi vsûs est *Historia Artium*; propterea quòd ostendat Res in Motu, & magis rectà ducat ad Praxin. Quinetiam tollit laruam & velum à Rebus Naturalibus, quæ plerunque sub varietate Figurarum & Apparentiæ externæ occultantur, aut obscurantur. Denique Vexationes Artis sunt certè tanquàm Vincula & Manicæ *Protei*, quæ vltimos Materiæ Nixus & Conatus produnt' (italics in original). Bacon uses the term 'betray' (*prodere*) to signify nature's disclosing her secrets against her will. In his philosophical reading of the myth of Proteus, Bacon draws an analogy between Proteus's deployment of his unused powers when bound and nature's capacity to transform itself into new species when vexed (See *De sapientia veterum*, in *SEH*, vol. 6, 725–726, cf. 651–652). For a detailed treatment of this myth see Weeks S., "Francis Bacon and the Art-Nature Distinction." For an alternative reading see Pesic P., "Wrestling with Proteus: Francis Bacon and the 'Torture' of Nature."

[125] Bacon, *Novum organum*, in *OFB*, vol. 11, 157: 'Quemadmodùm enim in Ciuilibus ingenium cuiusque, & occultus animi affectuûmque sensus meliùs elicitur, cùm quis in perturbatione ponitur, quàm aliàs: Simili modo, & occulta Naturæ magis se produnt per vexationes Artium, quàm cum cursu suo meant.'

[126] Bacon, *Distributio operis*, in *OFB*, vol. 11, 35: 'Itaque perceptioni Sensûs immediatæ ac propriæ non multùm tribuimus: sed eò rem deducimus, vt Sensus tantùm

Traditional natural histories may contain an inordinate quantity of observations but they are useless for Bacon's purposes:

> the worst thing about this abundance is that it has embraced the inquiry into things natural but largely spurned that into things mechanical. Now the latter are far better than the former for examining nature's recesses; for nature of its own accord, free and shifting, disperses the intellect and confuses it with its variety, but in mechanical operations the judgement is concentrated, and we see nature's modes and processes, not just its effects.[127]

This passage explains Bacon's claim that the mechanical arts engage the mind with things in motion. The important phrases are 'we see nature's modes and processes' and 'the judgement is concentrated.' For Bacon, knowledge of nature cannot be gained through merely observing nature free. Bacon's notion of using experiment (nature bound) to 'see nature's modes and processes' coheres well with Ursula Klein's statement that Hermann Boerhaave is following Bacon and Boyle when he 'ascribes to experiments the role of displaying the latent peculiar powers of bodies that cannot be observed directly by our senses.'[128] According to Boerhaave, chemical art 'discovers and lays before our eyes the very instruments whereby that powerful agent [nature] produces her effects, and thus leads us in her most secret ways, and often wisely directs them to our own uses.'[129] Boyle, moreover, was fully aware of Bacon's notion that the mechanical arts offer an engagement with 'things in motion.' He paraphrases Bacon when he states:

> the Phænomena of Trades are not only parts of the History of Nature, but some of them may be reckon'd among its more noble and usefull

de Experimento, Experimentum de Re iudicet.' According to Bacon, matter's hidden processes must be 'either laid bare to sense or forced into the light by evidence which can be submitted to sense' (*Redargutio philosophiarum*, in *BF*, 130, cf. *SEH*, vol. 3, 583). This is the role of experiment.

[127] Bacon, *Phænomena universi*, in *OFB*, vol. 6, 5. 'Pessimum autem est in hac copia, quod rerum Naturalium inquisitionem amplexa est, rerum autem Mechanicarum magna ex parte aspernata. Atque hæ ips*æ* ad Naturæ sinus excutiendos longè illis præstant; Natura enim sponte sua fusa & vaga disgregat Intellectum, & varietate sua confundit; verum in mechanicis operationibus contrahitur judicium, & naturæ modi & processus cernuntur, non tantum effecta.'

[128] Klein U., "Experimental History and Herman Boerhaave's Chemistry of Plants", *Studies in History and Philosophy of Biological and Biomedical Sciences* 34, 4 (2003) 533–567, on 548.

[129] Hermann Boerhaave, as quoted in Klein U., "Experimental History and Herman Boerhaave's Chemistry of Plants" 548.

> Parts. For they shew us Nature in *motion*, and that too when she is (as it were) put out of her Course, by the strength or skill of / Man, which [. . .] [is] the most instructive condition, wherein we can behold her.[130]

In the act of producing, the mechanical arts engage directly with a much reduced set of motions so that the judgement is concentrated. The experiments of the mechanical arts are a means of acquainting the mind with nature's hidden processes. Artisans (Bacon thinks) have no interest in the inquisitional attributes of experimentation; their main concern is the production of specific works. But were their attention to be diverted away from immediate needs, we would instead have a plethora of experiments capable of illuminating causes.

Bacon acknowledges the sceptical problem that the dizzying spectacle of nature is far too overpowering for the mind immediately to discover its hidden causes. But whereas nature free presents the judgement with matter's completed effects, the arts display 'things in motion.' In a mechanical operation the variety of nature's powers or motions are reduced to their constituent parts. The mechanical arts concentrate the judgement by displaying nature's hidden powers in a more accessible form. In this way, the mind is drawn nearer to the 'secret motions of things.'[131] Experimental practices bring matter's activities into the realm of judgement. Unlike nature free, they possess the power 'to inform the intellect.'[132] It is for this reason that Bacon insists on the inclusion of the mechanical arts in his primary history. The mechanical arts

> will giue a more true, and reall illumination concerning Causes and Axiomes, then is hetherto attained. For like as a Mans disposition is neuer well knowen, till hee be crossed, nor *Proteus* euer chaunged shapes, till hee was straightened and held fast: so the passages and variations of Nature cannot appeare so fully in the libertie of Nature, as in the trialls and vexations of Art.[133]

The mechanical arts lay bear nature's 'passages and variations' thereby offering an inroad into the hidden causes of things. The following section explains how Baconian inquiry extends the experiments of the

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[130] Robert Boyle, *The Usefulness of Experimental Natural Philosophy*, II,2 (1671), in *The Works of Robert Boyle*, vol. 6, 468 (italics in original). This passage is quoted in Rossi P., *Philosophy, Technology, and the Arts* 126.

[131] Bacon, *New Atlantis*, in *SEH*, vol. 3, 156.

[132] Bacon, *Novum organum*, in *OFB*, vol. 11, 157.

[133] Bacon, *Advancement of learning*, in *OFB*, vol. 4, 65 (italics in original).

mechanical arts and prepares the primary history for the next phase of inquiry.

4. *Experientia literata*

We saw in Part 2 that Baconian inquiry answers the question of invention. In *De augmentis scientiarum* Bacon identifies three modes of discovery: chance, the extension of former inventions (*experientia literata*), and the raising of axioms by means of *Novum organum*. As he puts it,

> all inventions of works which are known to men have either come by chance and so been handed down from one to another, or they have been purposely sought for. But those which have been found by intentional experiment have been either worked out by the light of causes and axioms, or detected by extending or transferring or putting together former inventions.[134]

According to Bacon, inventions of the mechanical arts such as the compass and artillery which 'seem to stand on certain hidden properties of things' have been stumbled upon by chance.[135] In contrast, printing 'involved nothing more than the combination of things already known, things that lay on the surface, as one might say.'[136] For Bacon, printing 'gives ground for hope that a vast number of inventions depend, not on the ferreting out of mysterious operations, but on the transference and application of processes already known.'[137] Bacon's concept of *experientia literata* facilitates this extension of former inventions. But what is its role in inquisitional terms?

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[134] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 366, cf. vol. 1, 572: 'Operum enim inventa omnia, quæ in hominum notitiam venerunt, aut casu occurrerunt et deinceps per manus tradita sunt, aut de industria quæsita. Quæ autem intentionaliter inventa sunt, illa aut per causarum et axiomatum lucem eruta sunt, aut per extensionem quandam vel translationem vel compositionem inventorum priorum deprehensa.'

[135] Bacon, *Novum organum*, in *OFB*, vol. 11, 169.

[136] Bacon, *Cogitata et visa*, in *BF*, 97, cf. *SEH*, vol. 3, 615: 'Imprimendi certe artem nihil habere, quod non sit apertum et fere obvium, et ex antea notis conflatum.' In *Novum organum* Bacon says, 'there is surely nothing belonging to the printer's trade which is not plain and pretty well obvious' (*OFB*, vol. 11, 169).

[137] Bacon, *Cogitata et visa*, in *BF*, 97, cf. *SEH*, vol. 3, 615: 'Atque hoc ipsum quoque ad spem trahebat, superesse nimirum adhuc magnum inventorum cumulum, qui non solum ex operationibus incognitis eruendis, sed et ex jam cognitis transferendis et applicandis deduci possit.'

There are two ways in which *experientia literata* contributes to inquiry. First, it generates *experimenta lucifera* (light-bearing experiments). Second, it serves as a ministration to memory in preparation for the work of 'interpretation' which follows.[138] With regard to the first aid to inquiry, *experientia literata* is a mode of invention that extends the primary history through generating *experimenta lucifera*. These, as explained above in Part 3, are 'experiments of no use in themselves but which only contribute to the discovery of causes.'[139] In characterising *experientia literata* as a mode of invention, Bacon calls this use of professional sagacity 'the Hunt of Pan' (*Venatio Panis*).[140] *Experientia literata* facilitates mechanically minded persons in extending invention: this seeking-out and widening of experimental data helps to broaden the materials of the primary history. With regard to the second function, *experientia literata* prepares the primary history for interpretation (the subject of *Novum organum*). The mind is unable to interpret unless the material is presented in an ordered form. Given the overpowering spectacle of the fecundity of nature, the mind cannot cope with the vast array of particulars composing the natural history unless, as Bacon puts it, 'it be set down and presented in suitable order.'[141] There must be a first digestion of materials to reduce the mind's confusion when confronted with the disorganised and seemingly infinite range of materials that constitute the primary history.[142] Thus there are two distinct inquisitional aids provided by *experientia literata*: it functions as a mode of invention, and as a first digestion of the natural-historical materials in preparation for the interpretation of nature. A failure to identify both these functions leads Farrington to complain of 'a slight confusion in [Bacon's] terminology' regarding *experientia literata*.[143] In Bacon's scheme, *experientia literata* is both a phase of inquiry in itself and an incipient part of a

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[138] For the meaning of the term 'interpretation' see n. 40.

[139] Bacon, *Novum organum*, vol. 11, 157–159.

[140] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 413, cf. vol. 1, 623. Pan is Bacon's figure for 'the Universe, or the All of Things.' In his interpretation of the fable of Pan he warns that inventions come 'only from Pan, that is from sagacious experience and the universal knowledge of nature; which oftentimes, by a kind of chance, and while engaged as it were in hunting, stumbles upon such discoveries' (*De augmentis scientiarum*, in *SEH*, vol. 4, 319, 326, cf. vol. 1, 522–523, 529).

[141] Bacon, *Novum organum*, in *OFB*, vol. 11, 215: 'nisi sistatur & compareat ordine idoneo.'

[142] See Bacon, *Novum organum*, in *OFB*, vol. 11, 159–161.

[143] Farrington B., *Francis Bacon* 111; see also idem, *BF*, 119, n. 2.

higher phase of inquiry (interpretation of nature) that culminates in the discovery of forms.

In its broadest sense, *experientia literata* refers to the primary history drawn into 'titles and tables.'[144] The tables bring 'all the experiments of all the arts [...] collected and arranged [*digesta*] [...] within one man's knowledge and judgment.'[145] By offering craftsmen a storehouse of previously scattered materials, *experientia literata* dissolves the boundaries of proprietorial and professional interests. As Lisa Jardine rightly says, '*experientia literata* is the material of the natural history organised in such a way as to suggest to a perceptive mind the possibilities for enlarging [experimental] knowledge by applying techniques successful in one field in similar fields, or by applying experiments successful on one type of material to similar materials.'[146] We saw in Part 3 that Bacon thinks much can be achieved 'by a free passage and transference of [...] thoughts.' This is the force of *experientia literata*; it facilitates the drawing of analogies that transcend the seclusion and isolation of the various arts. No phase of inquiry is divorced from the fundamental Baconian doctrine of the unity of nature, and the correlative doctrine of analogy. In specific terms, *experientia literata* puts the artisan's natural sagacity to better informative and indicatory use by incorporating the mechanical history within tables and thereby overcoming his narrow concentration on operations and techniques peculiar to his specific art. In Bacon's terms, 'by this translation (as I call it) of experiments the arts may mutually cherish and as it were kindle one another by mixture of rays.'[147] The force of *experientia literata* was not lost on Boyle who writes:

> And certainly, if so much as the known hints, that may be given by the Experiments already dispers'd among men of several Professions were known to any one man, though otherwayes but of common abilities; (as my own Experience has in some measure inform'd me) those united

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[144] Bacon, *New Atlantis*, in *SEH*, vol. 3, 164. On the influence of Bacon's titles on Boyle see Hunter M., "Robert Boyle and the Early Royal Society: A Reciprocal Exchange in the Making of Baconian Science", *British Journal for the History of Science* 40, 1 (2007) 1–23.

[145] Bacon, *Novum organum*, in *OFB*, vol. 11, 161: 'omnia omnium Artium Experimenta collecta & digesta fuerint, atque ad vnius hominis notitiam & iudicium peruenerint.'

[146] Jardine L., *Francis Bacon* 144.

[147] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 417, cf. vol. 1, 628. 'ut per hanc, quam dicimus, Experimentorum Translationem, artesse mutuo fovere et veluti commixtione radiorum accendere possint.'

> Beams, which scatter'd are scarce considerable, would afford him light enough to better most of the Particular Trades, that are Retainers to Philosophy.[148]

Bacon identifies eight ways of extending the mechanical history once it has been drawn into tables: 'The method of experimenting proceeds principally either by the Variation, or the Production, or the Translation, or the Inversion, or the Compulsion, or the Application, or the Conjunction, or finally the Chances [*Sortes*], of experiment.'[149] These are all means of translating the experiments of one art to others. Bacon stresses that 'none of these [modes of experimenting] however extend so far as to the invention of any axiom. For all transition from experiments to axioms, or from axioms to experiments, belongs to that other part, relating to the New Organon.'[150]

Yet although Bacon takes care to distinguish *experientia literata* from philosophical mechanics (which proceeds from axioms to experiments), many commentators confuse these categories. For example, William Eamon argues that 'Bacon characterized learned experience as an inductive methodology.'[151] According to Eamon,

> Bacon's learned experience [...] was essentially an attempt to define a rigorous methodology for conjecturing from the seen to the unseen aspects of nature, and from effects to causes [...]. He wanted to reduce cunning

[148] Robert Boyle, *The Usefulness of Experimental Natural Philosophy*, II,2 (1671), in *The Works of Robert Boyle*, vol. 6, 473. Elsewhere Boyle writes: 'It may serve to beget a Confederacy and an Union / between parts of Learning, whose possessors have hitherto kept their respective Skills strangers to one another; and by that means may bring great Variety of Observations and Experiments of differing kinds into the Notice of one man, or of the same persons; which how advantagious it may prove towards the Increase of knowledge, our Illustrious Verulam has somewhere taught us' (6: 402). Hunter notes that 'Boyle here cites the call for the unifying of the manual and intellectual spheres by Francis Bacon' but this is not the case (6: 402, n. b). Boyle is clearly drawing on Bacon's concept of *experientia literata*.

[149] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 413, cf. vol. 1, 624. 'Modus Experimentandi præcipue procedit, aut per Variationem Experimenti; aut per Productionem Experimenti; aut per Translationem Experimenti; aut per Inversionem Experimenti; aut per Compulsionem Experimenti; aut per Applicationem Experimenti; aut per Copulationem Experimenti; aut denique per Sortes Experimenti.' For a detailed account of these modes of experimenting see Jardine L., *Francis Bacon* 143–149; Eamon W., *Science and the Secrets of Nature: Books of Secrets in Medieval and Early Modern Culture* (Princeton, N.J.: 1994) 285–291; Anderson F.H., *The Philosophy of Francis Bacon* (Chicago: 1948) 284–288.

[150] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 413, cf. vol. 1, 624. 'Universa vero ista cohibita sunt citra Terminos Axiomatis alicujus inveniendi. Illa enim altera pars de Novo Organo omnem Transitionem Experimentorum in Axiomata, aut Axiomatum in Experimenta, sibi vindicat.'

[151] Eamon W., *Science and the Secrets of Nature* 287.

> to a rule, and to provide an orderly and systematic way of proceeding from particulars to axioms [...] [I]n Bacon's scheme [...] "sagacity" would be replaced by learned experience, an orderly method that began with the compilation of experiments and observations, then proceeded to the discovery of prerogative instances, and ended with the eduction of axioms and laws of nature.[152]

This cannot be the case since Bacon says *experientia literata* does *not* 'extend so far as to the invention of any axiom.' He characterises *experientia literata* as 'rather a sagacity and a kind of hunting by scent, than a science.'[153] The intellect is not involved at this incipient stage of inquiry.[154] On Eamon's reading, *Novum organum*, which does deal with the raising of axioms, is redundant. Eamon confuses *experientia literata* with a higher phase of inquiry (interpretation of nature) outlined in *Novum organum*. And he is not alone. Farrington, for instance, maintains that Agricola's *De re metallica* is 'the perfect example of what Francis Bacon later called *experientia literata*, or dumb practice which has been to school and learned to express itself in writing.'[155] But according to Bacon, Agricola handles 'that mechanic which is connected with physical causes.'[156] Agricola's work is philosophical mechanics—part of the interpretation of nature. If we are to grasp the role of mechanics in Bacon's programme, we must not blur the boundaries between *experientia literata* and interpretation. As shown above, Bacon's immediate successors such as Boyle were not misled and thus the confusion in Bacon commentary has repercussions for the historical characterisation of experimentation in this critically important period.

Having defined *experientia literata*, the remainder of this section will elaborate on its role in Bacon's Instauration. Jardine, who gives the most thorough treatment of this topic, presents *experientia literata* and *Novum organum* as 'conflicting strategies for dealing with the single problem of

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[152] Eamon W., *Science and the Secrets of Nature* 290.

[153] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 421, cf. vol. 1, 633. 'Atque de Literata Experientia hæc dicta sint, quæ (ut jam ante diximus) *Sagacitas* potius est et odoratio quædam venatica, quam *Scientia*' (italics in original).

[154] Spedding J. draws attention to Bacon's notion of *experientia literata* as a rudiment of interpretation but he wrongly interprets this to mean that the former 'necessarily implied some amount of *theory*' (*SEH*, vol. 1, 623, n. 1, italics in original). There is no theorising at this stage—connections are not made by the faculty of reason but by a lower faculty, common to humans and animals, which Bacon calls 'sagacity.'

[155] Farrington B., *BF*, 33.

[156] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 366, cf. vol. 1, 572: 'ea Mechanica, quæ cum Causis Physicis conjuncta est.'

scepticism concerning access to knowledge of natural phenomenon.'[157] Yet Bacon says *experientia literata* is 'but a degree and rudiment' of the interpretation of nature.[158] As mentioned, *experientia literata* contributes to Baconian inquiry in two ways: (1) it extends the primary history by supplying *experimenta lucifera*; (2) it functions as a ministration to memory for the interpretation of nature. *Experientia literata* also generates useful works (*experimenta fructifera*) but these are incidental to the goal of Baconian inquiry, viz., the production of *magnalia naturæ*. In what follows, I shall deal separately with the various functions of *experientia literata* to show that Bacon's terminology is not confused and that each aspect has its specific purpose.

The role of *experientia literata* in generating *experimenta lucifera* for the next phase of inquiry (interpretation of nature) has received scant attention. According to Farrington, *experientia literata* 'contents itself with "experiments of fruit" and does not rise to "experiments of light."'[159] By contrast, Jardine rightly notes that *experientia literata* contributes light-bearing experiments 'to the body of information concerning nature from which ultimately "true principles" will be derived,' yet she treats *experientia literata* and *Novum organum* as either/or strategies.[160] In *Novum organum* Bacon complains about the artisan's fixation on fruit-bearing rather than light-bearing experiments. This, he says, has been the ruination of experimental inquiry because resources have been misdirected into producing works when what is most requisite is to reveal 'nature's oracles.'[161] For Bacon, the interpretation of nature is the 'work of works' (*opus operum*) because it 'encompasses in itself all power.'[162] In his view, 'the very abundance of mechanical experiments reveals the dearth of those that contribute and help most for informing the intellect.'[163] Because the artisan does not care about 'investigating the truth,' he 'does not give his mind or reach out his hand to anything apart from

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[157] Jardine L., "*Experientia literata* or *Novum organum*? The Dilemma of Bacon's Scientific Method", in ed. W.A. Sessions W.A., *Francis Bacon's Legacy of Texts: 'The Art of Discovery Grows with Discovery'* (New York: 1990) 47–67, on 60–61.

[158] Bacon, *Advancement of learning*, in *OFB*, vol. 4, 111.

[159] Farrington B., *Francis Bacon* 111.

[160] Jardine L., "*Experientia literata* or *Novum organum*?" 56.

[161] Bacon, *Phænomena universi*, in *OFB*, vol. 6, 5.

[162] Bacon, *Phænomena universi*, in *OFB*, vol. 6, 5: 'omnem potestatem in se complectitur.'

[163] Bacon, *Novum organum*, in *OFB*, vol. 11, 157. 'Atque rursùs in ipsâ Experimentorum Mechanicorum copiâ, summa eorum quæ ad Intellectûs informationem maximè faciunt, & iuuant, detegitur inopia.'

what helps him in his work.'[164] But Baconian inquiry requires experiments whose only purpose is to illuminate causes. Hence Bacon says 'hope of further advancement of the sciences will be well grounded only when we take and gather into natural history many experiments of no use in themselves but which only contribute to the discovery of causes.'[165] For this reason, Bacon's inquisition prioritises light-bearing experiments over and above fruit-bearing ones. *Experientia literata* contributes experiments of light to the primary history. Hence Bacon concludes his discussion of *experientia literata* in *De augmentis scientiarum* with the following advice:

> no one should be disheartened or confounded if the experiments which he tries do not answer his expectation. For though a successful experiment be more agreeable, yet an unsuccessful one is oftentimes no less instructive. And it must ever be kept in mind (as I am continually urging) that experiments of Light are even more to be sought after than experiments of Fruit.[166]

The reader is left in no doubt as to the principal role of *experientia literata*, viz., the generation of light-bearing experiments. According to Bacon, what is needed is 'a class of experiments [. . .] which no one who was not pressing forward on a certain and direct road to the discovery of causes would have thought to investigate; for in themselves these things have no great use.'[167] As always, the end governs the means. The inter-

[164] Bacon, *Novum organum*, in *OFB*, vol. 11, 157. 'Mechanicus enim de veritatis inquisitione nullo modo sollicitus, non ad alia, quàm quæ operi suo subseruiunt, aut animum erigit, aut manum porrigit.'

[165] Bacon, *Novum organum*, in *OFB*, vol. 11, 157–159. 'Tum verò de Scientiarum vlteriore progressu Spes benè fundabitur, quùm in Historiam Naturalem recipientur & aggregabuntur complura Experimenta, quæ in se nullius sunt vsûs, sed ad inuentionem causarum & Axiomatum tantùm faciunt.'

[166] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 421, cf. vol. 1, 632–633. 'Illud interim circa hujusmodi Experimenta monemus; ut nemo animo concidat, aut quasi confundatur, si experimenta quibus incumbit expectationi suæ non respondeant. Etenim quod succedit magis complacet; at quod non succedit sæpenumero non minus informat. Atque illud semper in animo tenendum (quod perpetuo inculcamus,) Experimenta Lucifera etiam adhuc magis quam Fructifera ambienda esse.' See also *Novum organum*, in *OFB*, vol. 11, 159.

[167] Bacon, *Distributio operis*, in *OFB*, vol. 11, 41: 'planè conquirimus genus Experimentorum longè subtilius & simplicius quàm sunt ea quæ occurrunt [. . .] quæ nulli in mentem venisset inuestigare, nisi qui certo & constanti tramite ad inuentionem Causarum pergeret; cùm in se nullius magnoperè sint vsus.' These experiments, Bacon continues, 'are quite obviously not sought out for their own sake but stand in the same relation to things and works as the letters of the alphabet do to speech and words which, though useless in themselves, are still the fundamental elements of all discourse.'

pretation of nature, whose function is the discovery of causes, requires light-bearing experiments, and *experientia literata* puts the artisan's sagacity to better use in tracking these down.

Having discussed one inquisitional function of *experientia literata* (the generation of *experimenta lucifera*), I shall now address its utilitarian role. As already mentioned, *experientia literata* also generates useful works (*experimenta fructifera*). Although these are incidental to the goal of inquiry, Bacon acknowledges their utilitarian benefits. In *De augmentis scientiarum* he states:

> the best chance of bringing down as from heaven a shower of inventions at once useful and new, is to bring within the knowledge of one man, or of a few who may sharpen one another by conference, the experiments of a number of mechanical arts [...] For though the rational method [*Via Rationalis*] of inquiry by the Organon promises far greater things in the end, yet this sagacity proceeding by Learned Experience will in the meantime present mankind with a number of inventions which lie near at hand, and scatter them like the donatives that used to be thrown among the people.[168]

We find this idea in the *New Atlantis* where, once the primary history has been drawn into tables, Dowry-men or Benefactors 'bend themselves, looking into the experiments of their fellows, and cast about how to draw out of them things of use and practice for man's life, and knowledge [...].'[169] The Bensalamites reap the fruits of *experientia literata*—but these are not great inventions.[170] According to Bacon, 'all

[168] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 417, cf. vol. 1, 628–629. 'De his in genere monitum sit; quod nihil ad imbrem quendam inventorum utilium, eorundemque novorum, veluti cœlitus deducendum tantum valere possit, quantum si experimenta complurium artium mechanicarum uni homini, aut paucis qui se invicem colloquiis acuere possint, in notitiam venerint [...] Quamvis enim Via Rationalis per Organum longe majora spondeat, attamen hæc Sagacitas per Experientiam Literatam plurima interim ex iis quæ in proximo sunt in genus humanum (tanquam missilia apud antiquos donativa) projiciet et sparget.'

[169] Bacon, *New Atlantis*, in *SEH*, vol. 3, 165. Bacon uses the term 'dowries of nature' to refer to nature's works, see the dedicatory epistle prefaced to his *Advertisement touching an holy war* (*SEH*, vol. 7, 14).

[170] More work needs to be done on the role of charity in Bacon's programme. T. Paterson points out that purely selfish motives lead the Benefactors of Solomon's House 'to act as if they were in fact the humane and charitable scientist-saints of Baconian legend,' see "The Secular Control of Scientific Power in the Political Philosophy of Francis Bacon" 457. R. Kennington rightly argues that 'upon closer scrutiny it becomes clear that it is not Christian charity that persuades Bacon to endorse mastery of nature. Bacon's version of charity is much too worldly to be considered peculiarly biblical or Christian. As possible fruits of scientific mastery it features the extremes

the discoveries which we regard as more noble have (if you think about it) been brought to light *not at all* by minute elaborations and extensions of the arts [i.e., *experientia literata*] but entirely by chance.'[171] The fruits of *experientia literata* should not be confused with the goal of Baconian inquiry, namely, the production of *magnalia naturæ*. Of course, Bacon does not rule out experiments for profit.[172] The financial demands of the Instauration are significant; the construction of the primary history 'is a thing of exceedingly great mass and could not be accomplished without enormous effort and investment, for it requires an army of workers.'[173] Hence in *Novum organum* he states:

> If therefore a man is fitter and handier for the mechanical arts, and is good at hunting out works solely as a consequence of being conversant with experiments, I allow and leave to him the job of culling from my history and tables the many things that lie as by the wayside, and of applying them to works, and as it were acquiring interest for a time, until the capital can be had. But I, striving for greater prizes, renounce all precipitate and premature delays in this matter as if (as I generally say) they were Atalanta's apples.[174]

of pleasure, great engines of warfare, and indeed the pursuit of the immortality of the body in this life. Baconian charity is thoroughly humanistic.' *On Modern Origins: Essays in Early Modern Philosophy*, ed. by P. Kraus – F. Hunt (New York: 2004) 5. For alternative readings see Vickers B., "Bacon's So-called 'Utilitarianism': Sources and Influences", in M. Fattori (ed.), *Francis Bacon: terminologia e fortuna nel XVII secolo* (Rome: 1984), 281–313; Watanabe M., "Francis Bacon: Philanthropy and the Instauration of Learning", *Annals of Science* 49, 2 (1992) 163–173.

171 My trans. and emphasis, Bacon, *Novum organum*, in *OFB*, vol. 11, 302. 'Quocircà omnia Inuenta, quæ censeri possunt magis Nobilia (si animum aduertas) in lucem prodiêre, nullo modo per pusillas enucleationes & Extensiones Artium, sed omninò per Casum.'

172 Bacon's suggestions for experiments for profit include 'Making peas, cherries, and strawberries come early,' 'Making of candles to last long,' and 'Multiplying and dressing artichokes' (*Physiological Remains*, in *SEH*, vol. 3, 821–822).

173 Bacon, *Parasceve ad historiam naturalem*, in *OFB*, vol. 11, 451: 'quòd huiusmodi Historia, qualem animo metimur, & mox describemus, res perquàm magnæ sit Molis, nec sine magnis laboribus & sumptibus confici possit; vt quæ multorum operâ indigeat, & (vt alibi diximus) Opus sit quasi Regium.' In his reply to James' acknowledgement of *Novum organum*, Bacon says he hopes 'that your Majesty will be aiding to me, in setting men on work for the collecting of a natural and experimental history; which is *basis totius negotii* [the basis of the whole work] [...] that even in your times many noble inventions may be discovered for man's use. For who can tell, now this Mine of Truth is once opened, how the veins go, and what lieth higher and what lieth lower?' (*LL*, vol. 14, 130).

174 Bacon, *Novum organum*, in *OFB*, vol. 11, 177. 'Itaque si quis ad Mechanica sit magis aptus, & paratus, atque sagax ad venanda opera, ex conuersatione solâ cum Experimentis, ei permittimus & relinquimus illam industriam, vt ex Historiâ nostrâ, & Tabulis, multa tanquàm in viâ decerpat, & applicet ad Opera, ac veluti fœnus recipiat ad tempus, donec sors haberi possit. Nos verò, cùm ad maiora contendamus, moram omnem præproperam & præmaturam in istiusmodi rebus, tanquàm Atalantæ pilas (vt

Although Bacon allows the seeking out of fruit-bearing experiments, he argues that the temptation to chase after utilitarian benefits has had disastrous consequences for philosophy. This is the subject of the fable of Atalanta (as Bacon interprets it) who lost the race against Hippomenes because 'she, with a woman's eagerness, attracted by the beauty of the apple, left the course, ran after it, and stooped to take it up.'[175] There is, he says, 'not one of the sciences or arts which follows the true and legitimate course constantly forth till it reach its end; but it perpetually happens that arts stop in their undertakings half way, and forsake the course, and turn aside like Atalanta after profit and commodity.'[176] Hence Bacon repeatedly states, 'I do not chase like a child after golden apples [i.e., *experimenta fructifera*], but stake everything on a victory for art in its race against nature; nor do I rush off to mow the moss or green corn but wait for the ripened crop.'[177] The ripened crop refers to the fruits of 'true natural magic' which will speedily manifest great works. These will be things 'of a kind so very different and distant from things that were known before that absolutely no prior intimation could possibly have led to them […] secrets of excellent use which are quite unrelated to and unparalleled by anything already discovered.'[178] Bacon attempts to divert men's attention from *experimenta fructifera* by focusing their attention on the goal. Those who devote themselves to seeking out *experimenta lucifera* will, he says, 'be liberally recompensed in the end.'[179] They will receive the 'capital' rather than the 'interest.'

sæpiùs solemus dicere) damnamus.' On the fable of "Atalanta, or Profit" see Francis Bacon, *De sapientia veterum*, in *SEH*, vol. 6, 743–744, cf. 667–668.

[175] Bacon, *De sapientia veterum*, in *SEH*, vol. 6, 744, cf. 667–668: 'illa, cupiditate muliebri, et mali pulchritudine illecta, omisso stadio post malum cucurrit, et ad illud tollendum se submisit.'

[176] Bacon, *De sapientia veterum*, in *SEH*, vol. 6, 744, cf. 668. 'Neque reperitur ex scientiis aut artibus aliqua, quæ cursum suum verum et legitimum ad finem suum, tanquam ad metam, constanter produxerit; sed perpetuo artes incœpta præcidunt, et stadium deserunt, et ad lucrum et commodum declinant, instar Atalantæ.'

[177] Bacon, *Novum organum*, in *OFB*, vol. 11, 177. 'Neque enim aurea poma pueriliter affectamus, sed omnia in victoriâ cursûs Artis super Naturam ponimus; neque muscum, aut segetem herbidam demetere festinamus, sed messem tempestiuam expectamus.'

[178] Bacon, *Novum organum*, in *OFB*, vol. 11, 167–169: 'suntq*ue* illius (vt diximus) generis, vt ab ijs quæ anteà cognita fuerunt, planè heterogenea, & remotissima sint, vt prænotio aliqua nihil prorsùs ad illa conducere potuisset […] multa excellentis vsûs recondita, quæ nullam cum iam Inuentis cognationem habent, aut parallelismum.' Bacon stresses that the *magnalia* of nature are beyond human conception. Hence *experientia literata* cannot reach to these: 'no one contemplating the siege-engines and catapults of the ancients would ever, even if he spent a lifetime straining every nerve, have stumbled on the invention of weapons worked by gunpowder' (*Novum organum*, in *OFB*, vol. 11, 303).

[179] Bacon, *Valerius Terminus*, in *SEH*, vol. 3, 247.

Returning to the inquisitional role of *experientia literata*, in addition to supplying light-bearing experiments, *experientia literata* also functions as a 'ministration to memory' in preparation for the interpretation of nature.[180] According to Bacon, 'a man might as well attempt to go through the calculations of an Ephemeris in his head without the aid of writing, as to master the interpretation of nature by the natural and naked force of thought and memory, without the help of tables duly arranged [*tabulas ordinatas*].'[181] *Experientia literata* presents the primary history in a form which the intellect can get to grips with. He explains that

> *Natural* and *Experimental History* is so various and scattered that it may bewilder and distract the intellect unless it be set down and presented in suitable order. So we must fashion *Tables*, and *Structured Sets of Instances* [*Coordinationes Instantiarum*], marshalled in such a way that the intellect can get to work on them.[182]

Bacon maintains that 'we should have no good hopes for the [intellect's] cursory sorties and ineffectual flights, unless the particulars [...] be marshalled and drilled by appropriate tables of discovery, well drawn up and ready, so to speak, for action, and unless the mind buckle down to the organised assistance made ready by these tables.'[183] As William Rawley puts it, experience 'must be broken and grinded, and not whole, or as it groweth.'[184] Because the intellect (in Bacon's view) cannot digest the huge range of particulars which make up the primary history, the tables of *experientia literata* perform a first digestion. Philosophy, for Bacon, 'depends not only or mainly on the powers of the mind, nor

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[180] Bacon, *Novum organum*, in *OFB*, vol. 11, 215.

[181] Bacon, *De augmentis scientiarum*, vol. 4, 435, cf. vol. 1, 647. 'Tam enim possit quis calculationes Ephemeridis memoria nuda absque scripto absolvere, quam interpretationi naturæ per meditationes et vires memoriæ nativas et nudas sufficere; nisi eidem memoriæ per *tabulas ordinatas* ministretur' (italics in original).

[182] Bacon, *Novum organum*, in *OFB*, vol. 11, 215. '*Historia* verò *Naturalis* & *Experimentalis* tam varia est & sparsa, vt Intellectum confundat & disgreget, nisi sistatur & compareat ordine idoneo. Itaque formandæ sunt *Tabulæ*, & *Coordinationes Instantiarum*, tali modo & instructione, vt in eas agere possit Intellectus' (italics in original).

[183] Bacon, *Novum organum*, in *OFB*, vol. 11, 159–161. 'Atque insupèr, cùm tantus sit particularium numerus, & quasi exercitus, isq́ue ità sparsus & diffusus, vt Intellectum disgreget & confundat, de velitationibus, & leuibus Motibus, & transcursibus Intellectûs, non benè sperandum est; nisi fiat instructio & coordinatio per tabulas inueniendi idoneas, & benè dispositas, & tanquàm viuas, eorum quæ pertinent ad subiectum in quo versatur inquisitio, atque ad harum tabularum auxilia præparata & digesta, Mens applicetur.'

[184] William Rawley (letter prefaced to *Sylva sylvarum*) *SEH*, vol. 2, 336.

does it take the material gathered from natural history and mechanical experiments and store it unaltered in the memory but lays it up in the intellect changed and elaborated [*mutatam & subactam*].'[185] *Experientia literata* transforms the primary history prior to its being worked on by the intellect. This explains why Bacon designates *experientia literata* a 'rudiment' of interpretation: it is an incipient stage of interpretation.[186] *Experientia literata* helps to overcome the dazzling and numbing effect of nature's overwhelming fecundity through the organisational capacity of the tables.

5. *Philosophical Mechanics*

The next phase of inquiry is the interpretation of nature proper—the ascent to forms via the *scala intellectus* (ladder of the intellect).[187] As we have seen, Baconian knowledge ascends through a series of axioms of expanding generality, whose scope is determined by the science from which they are derived.[188] Whereas physics ascends to lower and middle axioms, metaphysics ascends to 'axioms of the highest generality' (forms).[189] Bacon regards philosophical mechanics as the science which refines axioms of physics through experiment.[190] Following every ascent

[185] Bacon, *Novum organum*, in *OFB*, vol. 11, 153. 'Neque absimile Philosophiæ verum opificium est; quod nec Mentis viribus tantùm aut præcipuè nititur, neque ex Historia Naturali & Mechanicis Experimentis præbitam materiam, in Memoriâ integram, sed in Intellectu mutatam & subactam reponit.'

[186] This also explains why Bacon says that 'if things are so arranged [...] people, freed both from the hobgoblins of belief and blindness of experiments, may enter into a more reliable and sound partnership with things by, as it were, a certain literate experience [*ipsi cum rebus magis fida & magis arcta inita societate contrahunt, quasi per experientia*m *quanda*m *literatam*]. For in this way the intellect is both set up in safety and in its best state, and it will besides be at the ready and then come upon harvests of useful things' (*Phænomena universi*, in *OFB*, vol. 6, 3).

[187] The *Scala intellectus* is Part 4 of Bacon's *Instauratio magna*. See *Distributio operis*, in *OFB*, vol. 11, 27.

[188] For a discussion of Bacon's division of the sciences see Kusukawa S., "Bacon's Classification of Knowledge", in Peltonen M. (ed.), *The Cambridge Companion to Bacon* (Cambridge: 1996) 47–74.

[189] Bacon, *Novum organum*, in *OFB*, vol. 11, 71.

[190] In *De augmentis scientiarum* Bacon suggests that we divide 'Natural Philosophy into two parts, the mine and the furnace; and make two professions or occupations of natural philosophers, some to be miners and some to be smiths.' In other words, natural philosophy should 'be divided into the Inquisition of Causes, and the Production of Effects; Speculative and Operative. The one searching into the bowels of nature, the other shaping nature as on an anvil [*Altera naturæ viscera perscrutatur; altera naturam veluti*

of the mind to an axiom, there must be a descent via experimentation to things, thereby guaranteeing the continual union of things (*res*) and mind (*mens*). Bacon states time and again that his 'route is not laid on the flat but goes up and down—ascending first to axioms, and then descending to works.'[191] According to Bacon, 'all true and fruitful Natural Philosophy has a double scale or ladder going in different directions, ascendent and descendent.'[192] Unlike the empiric who extracts 'works from works, or experiments from experiments,' Bacon's procedure is to extract 'from works and experiments causes and axioms, and in turn from causes and axioms new works and experiments.'[193] This principle has not received the scholarly attention that it merits, given that Baconian inquiry is unthinkable without it. The theoretical ascent from experiments of light to causes and axioms is the domain of physics and metaphysics; the operative descent to new works and experiments is the domain of mechanics and magic. As Fulton Anderson has astutely pointed out, Bacon regards "magic" as generalized mechanics and the operative counterpart of metaphysics.'[194] The role of philosophical mechanics—by its continual descent from axioms to experiments—is to sustain the union of *res* and *mens*.

Because the crucial role of philosophical mechanics has not been examined, an entire stage of Baconian inquiry has been overlooked.[195]

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super incudem efformat]' (*SEH*, vol. 4, 343, cf. vol. 1, 547). Physics investigates causes and philosophical mechanics executes experiments for the purpose of refining axioms.

[191] Bacon, *Novum organum*, in *OFB*, vol. 11 161. 'Neque enim in plano via sita est, sed ascendendo, & descendendo; Ascendendo primò ad Axiomata, Descendendo ad Opera.'

[192] My trans., Bacon, *De augmentis scientiarum*, in *SEH*, vol. 1, 547. 'Attamen quandoquidem omnis solida et fructuosa Naturalis Philosophia duplicem adhibeat scalam, eamque diversam; *Ascensoriam* et *Descensoriam*; ab *Experientia* ad *Axiomata*, et ab *Axiomatibus* ad *nova Inventa*' (italics in original).

[193] Bacon, *Novum organum*, in *OFB*, vol. 11, 175. 'Verùm via nostra, & ratio [. . .] ea est; vt non Opera ex Operibus, siue Experime*n*ta ex Experimentis (vt Empirici) sed ex operibus & Experimentis Causas & Axiomata, atque ex Causis & Axiomatibus, rursùs noua Opera & Experimenta (vt legitimi Naturæ Interpretes) extrahamus.'

[194] Anderson F.H., *Francis Bacon: His Career and his Thought* (Toronto: 1962) 18. Bacon makes this clear in the marginalia of *Advancement of learning* where he designates natural magic '*Physica Operatiua Maior*' (*OFB*, vol. 4, 89). Philosophical mechanics, for Bacon, is minor operative physics.

[195] Bacon's philosophical mechanics bears little resemblance to the more geometrical and mathematical style of the Italian theorists that culminated in the work of figures such as Galileo. For an excellent survey of the rise of mechanics as an independent *scientia* within natural philosophy see Laird W.R., "The Scope of Renaissance Mechanics", *Osiris*, new series 2 (1986) 43–68. Apart from the retention of the notion of useful work, Baconian mechanics diverges significantly from this emerging theoretical science.

The cause of this oversight may be that Bacon has little use for the emerging science of mathematically based mechanics.[196] Stephen Gaukroger, for example, whilst fully appreciating the importance of Bacon's theory of matter, segregates it from mechanics:

> Eschewing mechanics, he [Bacon] pursues natural philosophy exclusively through matter theory, arguing that the mathematical treatment characteristic of mechanics only touches the periphery, whereas accounting for the behaviour of physical bodies in terms of their constituent corpuscles reveals what lies at the basis of that behaviour, and so ultimately enables us to manipulate it.[197]

Leaving aside Gaukroger's misapplication of corpuscular theory to Bacon, his dismissal of Baconian mechanics is peremptory. It disregards the crucial role of philosophical mechanics in the construction of axioms.[198] The mathematical treatment of bodies typified in the emerging *scientia* of mechanics abstracts motions from material causes for the purpose of representing them in geometrical or mathematical models. In contrast, Bacon's science of mechanics deals directly with matter's hidden virtues in the realm of operation. As mentioned, Bacon locates philosophical mechanics in the tradition that includes among others Aristotle, Hero and Agricola, specifically because they investigated causes.[199] In philosophical mechanics we find the intersection of

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Laird demonstrates the crucial role of commentary on the Pseudo-Aristotelian *Questions in Mechanics* in the emergence of mechanics as an independent *scientia*. Spedding notes that when Bacon, in *De augmentis scientiarum*, refers to 'Aristotle' he is actually referring to the Pseudo-Aristotelian *Mechanical Problems*, another influential text that helped promote Renaissance mechanics (see *SEH*, vol. 1, 572, n. 1). Although Bacon refers to this text as an example of his third kind of mechanics, his understanding of philosophical mechanics is at odds with this nascent *scientia*, especially over the role of mathematics in inquiry.

[196] On Bacon and mathematics see Rees G., "Quantitative Reasoning in Francis Bacon's Natural Philosophy", *Nouvelles de la république des lettres* (1985) 27–48; Idem, "Mathematics and Francis Bacon's Natural Philosophy", *Revue internationale de philosophie*, 159 (1986) 399–426.

[197] Gaukroger S., *Francis Bacon and the Transformation of Early-Modern Philosophy* (Cambridge: 2001) 93.

[198] Even Rossi has overlooked the crucial role of axioms as a theoretical feature of Baconian inquiry. According to Rossi, 'the limits of the Baconian method derive, no doubt, from an insufficient appraisal of the function performed, in the realm of scientific cognition, by hypotheses, by the "anticipation of the experiment," and by axiomatic systems of a deductive character,' *Philosophy, Technology, and the Arts* 116–117. In contrast, I argue that all of the above play a role in the interpretation of nature.

[199] See Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 366, cf. vol. 1, 572. Whether or not Bacon is justified in drawing on this illustrious lineage, the point stands that he defines the task of philosophical mechanics to be the same as theirs, that is, the pursuit

technical know-how (praxis) and knowledge of causes. Rossi's summary of Agricola's position illustrates this connection: 'A metallurgist must be expert at identifying soils, at distinguishing seams, stones, precious stones, and metals, and he must be acquainted with "every possible manner of experimenting with the materials at hand." But he must also be versed in philosophy "so that he may understand the origins, causes, and nature of subterranean things."'[200]

Sachiko Kusukawa, following the excellent treatment of W.R. Laird, points out that 'Bacon was of the generation for whom mechanics had already emerged as a new discipline. In the sixteenth century, mechanics (hitherto considered as a manual art) had received new impetus first by the rediscovery and assimilation of (pseudo-) Aristotle's *Questions of Mechanics* and then by a widening of its scopes by assimilating other types of problems.'[201] Bacon's philosophical mechanics cannot be divorced from knowledge of physical causes since it is essentially operative physics.[202] It is this emphasis on operation rather than mathematical description which grounds philosophical mechanics in knowledge of causes and determines Bacon's radical move of incorporating mechanics within natural philosophy. Unlike the mathematical abstractions of Galilean physics, Baconian physics proceeds by way of 'concrete bodies as we find them in nature in her ordinary course.'[203] But there is a great difference between the engagement with nature at the level of natural history and the engagement with nature at the level of physics. Bacon is unambiguous on this important distinction: 'Natural History investigates and relates the fact, whereas Physic likewise examines the

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of physical causes. For an excellent discussion of Hero and mechanics see Tybjerg K., "Wonder-Making and Philosophical Wonder in Hero of Alexandria", *Studies in History and Philosophy of Science*, 34, 3 (2003) 443–466. Tybjerg argues that 'the concept of wonder plays a pivotal role in Hero's promotion of mechanics as a form of knowledge that is elevated above manual work and that holds a epistemological status on a par with—or even superior to—that of philosophy,' 445.

[200] Agricola, as quoted in Rossi P., *Francis Bacon* 5. For a discussion of causes in Agricola see the lengthy translators' note in *Georgius Agricola De Re Metallica*, transl. by H.C. Hoover and L.H. Hoover (New York: 1950) 43–53, n. 1.

[201] Kusukawa S., "Bacon's Classification of the Sciences" 59.

[202] As noted above, Bacon (in the marginalia of *Advancement of learning*) designates natural magic '*Physica Operatiua Maior*' (*OFB*, vol. 4, 89). In Bacon's scheme, philosophical mechanics is minor operative physics.

[203] Bacon, *Novum organum*, in *OFB*, vol. 11, 207: 'per concreta corpora, quemadmodùm in Naturâ inueniuntur, cursu ordinario.'

causes.'[204] Physics investigates what Bacon calls 'latent process' (*latens processus*) and 'latent schematism' (*latens schematismus*).[205] Very briefly, latent process refers to the hidden process of motions 'carried on from manifest efficient cause and manifest material cause all the way to the form implanted.'[206] For example, it investigates 'from what beginnings, by what means and by what process gold or any other metal or stone is generated, starting with its first menstrua or rudiments, all the way up to the finished mineral.'[207] Latent schematism, on the other hand, investigates the hidden 'anatomy' of 'bodies at rest and not in motion.'[208]

The discovery of latent process and latent schematism leads to the formulation of axioms. For example, Bacon investigates vivification 'by careful noting of the first beginnings and rudiments or attempts of life in animalcules born of putrefaction, as in ants' eggs, worms, flies, frogs after rain, etc.'[209] On the basis of his investigation of this latent process, Bacon extracts 'the great axiom of vivification.'[210] Namely, 'there must be heat to dilate the spirit of the body; an active spirit to be dilated; matter viscous or tenacious to hold in the spirit; and that matter to be put forth and figured.'[211] Once again analogy is at work. Bacon thinks the investigation of creatures bred of putrefaction will disclose 'many things in the nature of perfect creatures, which in them lie more hidden.'[212] It should be noted that the investigation itself of latent process and latent schematism only gives us more knowledge of latent process and latent schematism. None of this knowledge is axiomatic: it is merely providing physical information about the ordinary course of nature. Axioms result from the union of *res* and *mens*; they

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[204] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 347, cf. vol. 1, 551. 'Etenim in hisce omnibus Historia Naturalis factum ipsum perscrutatur et refert, at Physica itidem causas.'

[205] Bacon, *Novum organum*, in *OFB*, vol. 11, 201.

[206] Bacon, *Novum organum*, in *OFB*, vol. 11, 201: 'continuati ab Efficiente manifesto, & Materiâ manifestâ, vsquè ad Formam inditam.'

[207] Bacon, *Novum organum*, in *OFB*, vol. 11, 207: 'ex quibus initijs, & quo modo, & quo processu, Aurum, aut aliud quoduis metallum, aut lapis generetur, à primis menstruis, aut rudimentis suis, vsque ad Mineram perfectam.'

[208] Bacon, *Novum organum*, in *OFB*, vol. 11, 201, 211. 'Corporum quiescentium, & non in Motu.'

[209] Bacon, *Novum organum*, in *OFB*, vol. 11, 351: 'per notationes diligentes primorum incœptuum, & rudimentorum siue tentamentorum vitæ in Animalculis ex Putrefactione natis: vt in ouis Formicarum, Vermibus, Muscis, Ranis post imbrem, &c.'

[210] Bacon, *Sylva sylvarum*, in *SEH*, vol. 2, 559.

[211] Bacon, *Sylva sylvarum*, in *SEH*, vol. 2, 559. See also *Novum organum*, in *OFB*, vol. 11, 351; *Historia & inquisitio de animato & inanimato*, in *OFB*, vol. 13, 233–235.

[212] Bacon, *Sylva sylvarum*, in *SEH*, vol. 2, 557.

are not simply given by physics as if they were a constituent among things, rather they must be induced on the basis of what physics has investigated. In the *New Atlantis* fellows of Solomon's House 'direct new experiments, of a higher light, more penetrating into nature' than those of experimental history and *experientia literata*.[213] Interpreters of nature then 'raise the former discoveries by experiments into greater observations, axioms, and aphorisms.'[214]

When it comes to raising axioms, 'the understanding is endowed by nature with an evil impulse to jump from particulars to the highest axioms.'[215] This impulse, Bacon says, 'must be held in check; but generalisations lying close to the facts must first be elicited and discovered, then generalisations of a middle sort, and progress thus achieved up the successive rungs of a genuine ladder of the intellect.'[216] In *Novum organum* Bacon speaks of the need to supply the understanding 'with leaden weights to curb all jumping and flying up.'[217] In practice, these weights take the form of further experiments. As noted above, every ascent of the mind to an axiom must of necessity be followed by a descent via experimentation to things, thus assuring the union of *res* and *mens*. It is precisely for this purpose that philosophical mechanics seeks out *experimenta lucifera*. By introducing the concept of *experimenta lucifera*, Bacon effectively redefines the science of mechanics since its goal is no longer works (*experimenta fructifera*). Rather,

> the legitimate interpretation of nature, rightly conducted, ought in the first steps of the ascent, until a certain stage of generals be reached, to be kept clear of and distinct from all application to works. Indeed I know that all those who have ventured themselves at all upon the waves of experience since they were either too weak of purpose or too eager

[213] Bacon, *New Atlantis*, in *SEH*, vol. 3, 165.

[214] Bacon, *New Atlantis*, in *SEH*, vol. 3, 165.

[215] Bacon, *Cogitata et visa*, in *BF*, vol. 99, cf. *SEH*, vol. 3, 618. 'Visum est ei, Intellectus motum et impetum naturalem, sed pravum, a particularibus ad comprehensiones supremas et generalissimas [...] saliendi.'

[216] My trans., Bacon, *Cogitata et visa*, in *SEH*, vol. 3, 618: 'omnino cohibendum: sed comprehensiones proximas primo, ac deinceps medias, eliciendas et inveniendas, atque per gradus continuos et scalam veram procedendum.'

[217] Bacon, *Novum organum*, in *OFB*, vol. 11, 163. 'Itaque hominum Intellectui non plumæ addendæ, sed plumbum potiùs, & pondera; vt cohibeant omnem saltum & volatum.'

> for display, have at the outset sought prematurely for pledges of works, and by that have been wrecked and cast away.[218]

In *De sapientia veterum* Bacon presents the fable of Orpheus. Orpheus (Bacon's figure for universal philosophy) lost Eurydice because 'in the impatience of love and anxiety' he looked back before he reached the light.[219] As Bacon interprets this, philosophy fails 'from no cause more than from curious and premature meddling and impatience.'[220] The Baconian inquirer must refrain from 'application to works' (*experimenta fructifera*) until he arrives at knowledge of forms.

Philosophical mechanics executes light-bearing experiments for the purpose of refining axioms. The operative element ensures that axioms demonstrate a real causal property in matter. Baconian philosophy does not '[...] catch and hold abstract things with the mind's fragile tendrils (as common logic does), but really [...] slice[s] into nature [...].'[221] Along with a doctrine of error, which Bacon outlines in Book 1 of *Novum organum*, he also provides a criterion of truth. The mind accesses truth via Baconian matter and its possibilities, and certainty derives from operation, not demonstration. In Baconian terms, truth is discovered not through discursive argumentation but through operative (experimental) engagement with nature leading to 'new particulars'—novel effects and works.[222] This is only possible by means of a continual movement between theory and practice which ensures the union of *res* and *mens*. The distinguishing mark of Bacon's criterion of truth is its incorporation of error and negativity as the cybernetic means of control over inquiry.[223] There

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[218] My trans., Bacon, *De interpretatione naturæ proœmium*, in *SEH*, vol. 3, 520. 'Ac eodem candore profiteor, interpretationem naturæ legitimam, in primo adscensu antequam ad gradum certum generalium perventum sit, ab omni applicatione ad opera puram ac sejunctam servari debere. Quin et eos omnes qui experientiæ se undis aliqua ex parte dediderunt, cum animo parum firmi aut ostentationis cupidi essent, in introitu operum pignora intempestive investigasse, et inde exturbatos et naufragos fuisse scio.'

[219] Bacon, *De sapientia veterum*, in *SEH*, vol. 6, 720, cf. 647.

[220] Bacon, *De sapientia veterum*, in *SEH*, vol. 6, 722, cf. 648: 'idque [...] non magis aliam ob causam, quam per curiosam et intempestivam sedulitatem et impatientiam.'

[221] My trans., Bacon, *Novum organum*, in *OFB*, vol. 11, 442. 'Sed cùm Logica nostra, doceat Intellectum & erudiat ad hoc, vt non tenuibus Mentis quasi Clauiculis rerum Abstracta captet & prenset (vt Logica vulgaris) sed Naturam reuerâ persecet, & Corporum virtutes & Actus, eorumque Leges in Materiâ determinatas inueniat.'

[222] Bacon, *Novum organum*, in *OFB*, vol. 11, 73.

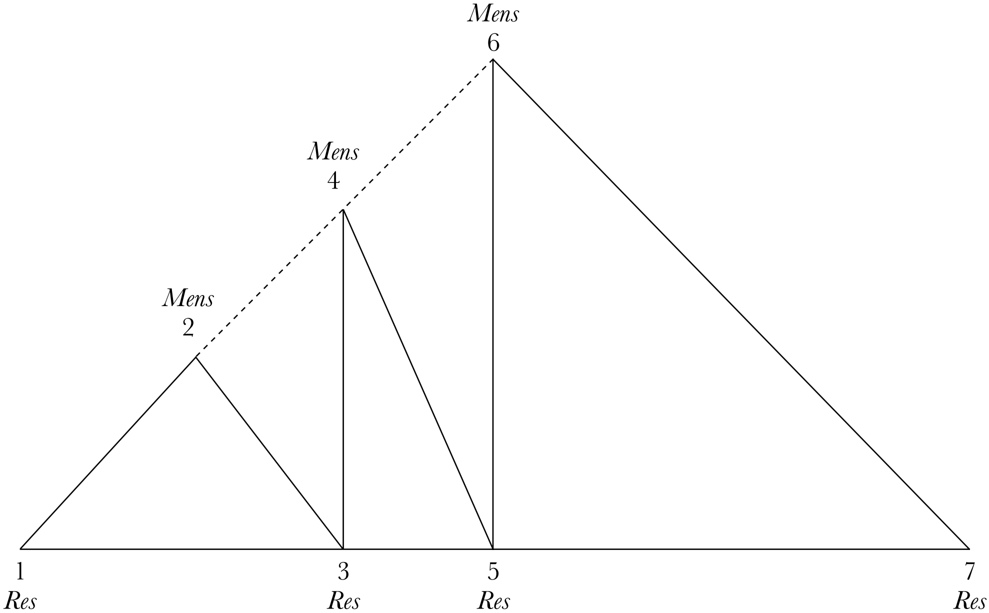
[223] Justification for characterising Baconian inquiry as 'cybernetic' is given by the term's etymology, from the Greek κυβερνήτης (*kybernetes*, steersman, governor, pilot, or rudder—the same root as government). Bacon's feedback strategy cannot be predetermined but is responsive to specific contexts. This, according to Bacon, is what is absent

are two strategies involved in the establishing of axioms which serve to highlight the cybernetic nature of Baconian inquiry. First, the range of information assembled forms the input and its structuring in tables (*experientia literata*) provides the equivalent of a directing mechanism, in the sense of homing in on a target. Second, the experimental attempt to confirm the axiom provides the feedback. The positive feedback (production of *nova*) from the experimental testing is the guarantee that the investigation is still pursuing its target in nature. The goal or target must always be confined to something in nature (*res*). At every stage of the axiomatic ladder, Baconian inquiry involves descent to works to ensure that the mind (*mens*) is still in contact with things (*res*). Philosophical mechanics extracts experiments from physical axioms in order to provide this essential feedback. Without implementing this to and fro movement between generalisations and feedback, there is no way of making sure that the mind (*mens*) is still in contact with things (*res*). (See Figure 2.) Interpretation of nature is a continual play of error correction that produces a cybernetic epistemology, guaranteed to find the target. The inquisition of nature is completely dependent on this feedback epistemology where questions are designed to elicit answers that determine further questions, and where the feedback loop can eliminate error.

The foregoing account explains why Bacon thinks his proposed procedures lead to certainty.[224] His self-presentation as radical reformer rests

in traditional systems of dialectic. For this reason, commentators should be cautious in translating Baconian inquiry into more familiar but ill-fitting formalised or methodical moulds. The classical sceptical notion of 'zetetic inquiry' is more appropriate and closer to Baconian inquisitional procedures than modern conceptions of eliminative induction. Given that Baconian inquiry is heuristic, it could be appropriately named a 'zetetic heuristic.' There are many classical antecedents for the term 'cybernetic.' On the Greek side see Homer, *Odyssey*, Bk. 11, line 10; Sophocles, *Oedipus Tyrannus*, 922; Euripides, *Suppliants*, 879; Aeschylus, *Suppliant Women*, 769; Plato, *Gorgias*, 511d, where he speaks of the "steersman of the soul"; Aristotle, *Politics*, 1279a. For the Latin equivalent *gubernator* see Caesar, *De bello civili*, 1, 58, 1; Cicero, *Epistulæ ad familiares*, 2, 6; Plautus, *Miles gloriosus*, 4, 4, 40. This list is found in Conway F. – Siegelman J., *Dark Hero of the Information Age: In Search of Norbert Wiener, the Father of Cybernetics* (New York: 2005) 372–373.

[224] The grounds for Bacon's belief that his procedures lead to certainty have been ignored in attempts to reduce the so-called method to the formal procedures of eliminative induction or some form of hypothetico-deduction. Defending the latter, Peter Urbach objects to this central Baconian assumption, viz., that certainty is guaranteed, *Francis Bacon's Philosophy of Science: An Account and a Reappraisal* (La Salle: 1987). Urbach recognises that Bacon's notion of fallibility is provisional, but he elevates this to a fixed methodology of fallibility *per se*. However, Bacon's understanding of fallibility is



1. *experimenta lucifera*
2. lower axiom
3. new particulars (*experimenta lucifera*)
4. middle axiom
5. new particulars (*experimenta lucifera*)
6. primary axiom/form
7. magical works (*experimenta fructifera*)

Fig. 2. The double ladder of the intellect.

on the claim that he alone knows the true goal of philosophy. This (he thinks) is the difference between him and all who have gone before. '*The end and scope of knowledge*,' he says, '*hath been generally mistaken*.'[225] According to Bacon, those who have sought knowledge have 'propounded to themselves a wrong mark, namely satisfaction (which men call truth) and not operation.'[226] In the early *Mr. Bacon in praise of knowledge* he asks, 'Is

pragmatic and provisional, and (as shown above) is principally a procedure of error-correction. Bacon's doctrine of error relates to his account of the genetic source of the mind's declination. Experiment realigns the mind through the signs and marks provided by *nova*. Error is sustained in demonstrative systems because of the lack of direction or guidance through nature's tortuous labyrinth.

[225] Bacon, *Valerius Terminus*, in *SEH*, vol. 3, 231 (italics in original).

[226] Bacon, *Valerius Terminus*, in *SEH*, vol. 3, 232.

truth ever barren? Shall [man] not be able thereby to produce worthy effects, and to endow the life of man with infinite commodities?'[227] The purpose of Baconian inquiry is to acquire knowledge of causes (forms) which can be used to produce unparalleled works. Bacon's aim is knowledge of 'such causes as will direct him and give him light to new experiences and inventions,' not 'such causes as will satisfy the mind of man and quiet objections.'[228] This notion relates to Bacon's doctrine of the unexploited potentiality of matter. For Bacon, the goal is the actualisation of *nova*—the shaking out of nature's hidden folds. *Nova* provide the Baconian inquirer with a determinable direction, and function as his criterion of truth. In *Novum organum* he explains,

> in nature practical results [*opera*] are not only the means to improve well-being but the guarantee of truth [*veritatis pignora*]. The rule of religion, that a man should show his faith by his works, holds good in natural philosophy too. Science also must be known by works. It is by the witness of works, rather than by logic or even observation, that truth is revealed and established. Whence it follows that the improvement of man's mind and the improvement of his lot are one and the same thing.[229]

This is the meaning of the well known phrase '*ipsissimæ Res sunt* [...] *Veritas & Vtilitas*' ('the very things themselves are [...] truth and utility').[230] When we return the phrase to its original context in *Novum organum* it is clear that Bacon is expressing his criterion of truth:

> *Itaque ipsissimæ Res sunt (in hoc genere) Veritas & Vtilitas: atque Opera ipsa pluris facienda sunt, quatenùs sunt veritatis pignora, quàm propter vitæ commoda.*
>
> And so the very things themselves are (in this case) truth and utility: and works themselves are, to the extent that they are pledges of truth, to be made more of than because they bring comforts to life.[231]

[227] Bacon, *Mr. Bacon in praise of knowledge*, in *LL*, vol. 8, 123.

[228] Bacon, *Valerius Terminus*, in *SEH*, vol. 3, 232.

[229] Bacon, *Cogitata et visa*, in *BF*, vol. 93, cf. *SEH*, vol. 3, 612. 'etenim in natura, opera non tantum vitæ beneficia, sed et veritatis pignora esse. Et quod in religione verissime requiritur, ut fidem quis ex operibus monstret; idem in naturali philosophia competere, ut scientia similiter ex operibus monstretur. Veritatem enim per operum indicationem, magis quam ex argumentatione aut etiam ex sensu, et patefieri et probari. Quare unam eandemque rationem et conditionis humanæ et mentis dotandæ esse.'

[230] My trans., Bacon, *Novum organum*, in *OFB*, vol. 11, 186. Rossi points out that this phrase has been wrongly translated and offers an accurate rendering, *Philosophy, Technology, and the Arts* 157–160.

[231] My trans., Bacon, *Novum organum*, in *OFB*, vol. 11, 186.

For Bacon, truth and utility correspondently reside in *res* (matter); they are not made by man, but discovered. Philosophical mechanics executes *experimenta lucifera* which, if they give rise to new particulars (*opera*), function as 'pledges of truth.'

Physics ascends to an axiom; if the axiom is true it will specify new particulars—it will extend to the discovery of *nova*. An axiom (for Bacon) is a way of expressing nature's fecundity in philosophical doctrine. Because nature acts 'according to law' (*ex lege*), its modes of operation can be expressed in doctrine.[232] A Baconian axiom is a rule or law unifying nature's behaviour. At the level of physics we are dealing with 'the particular and special habits of nature,' which can be expressed as rules.[233] Nature's effects are an explication of the rule, that is, a description of nature's unfolding. This is clear in *Historia vitæ et mortis* where each of the 'provisional rules' (*canones mobiles*) is followed by an 'explication' (*explicatio*) which details the various effects which flow from the rule, and from which the rule is derived.[234] The greater the generality of the rule, the more effects it encompasses (or unifies) and these effects may be actual or potential. Hence a Baconian axiom will not only explain 'the particulars whence it is derived,' but also specify potential new particulars.[235] The rules of physics are lower or middle axioms. Lower axioms hardly differ from bare experience; they therefore have little operative value. Middle axioms, however, have a wider scope. They unify a range of natural phenomena and will therefore specify a range of potential new particulars. As Bacon explains,

> in setting up axioms with this form of induction, we must check and see whether the axiom so set up be appropriate and made only to the measure of the particulars whence it is derived, or whether it is fuller and more extensive. Now if it is fuller and more extensive, we must see whether that amplitude and latitude be confirmed, as if by a kind of guarantee [*quasi fide-iussione quâdam*], by the specification of new particulars, lest we

[232] Bacon, *Novum organum*, in *OFB*, vol. 11, 203.
[233] Bacon, *Novum organum*, in *OFB*, vol. 11, 209: 'consuetudines Naturæ particulares, & speciales.'
[234] My trans., Bacon, *Historia vitæ et mortis*, in *SEH*, vol. 5, 320–335, cf. vol. 2, 212–226.
[235] Bacon, *Novum organum*, in *OFB*, vol. 11, 163–165. In *Cogitata et visa* Bacon explains, 'A valid axiom [...] should not be narrowly cut to the measure of the facts from which it is drawn. It should have a more ample scope, permitting the inclusion of new facts under it by which its final limits would be fixed' (*BF*, 99–100, cf. *SEH*, vol. 3, 618). In other words, a valid axiom should not only explain the particulars from which it is derived, but should also specify new particulars.

> either cling only to things known already, or perhaps with slacker grasp catch hold of shadows and abstract forms, and not of things solid and bound in matter.[236]

Philosophical mechanics checks whether an axiom does in fact discover new particulars. However, the discovery of new particulars does not mean that an axiom is certainly true—it merely indicates that we are possibly on the right path. Although we ought to pay heed to affirmatives, 'in the setting up of every true axiom, the power of the negative instance is greater.'[237]

Bacon's procedures are cybernetic by virtue of his asymmetrical criterion of truth which incorporates negativity in an error-correcting procedure. He states:

> the discovery of new works and active directions not known before, is the only trial to be accepted of; and yet not that neither, in case where one particular giveth light to another; but where particulars induce an axiom or observation, which axiom found out discovereth and designeth new particulars. That the nature of this trial is not only upon the point, whether the knowledge be profitable or no, but even upon the point whether the knowledge be true or no; not because you may always conclude that the Axiom which discovereth new instances is true, but contrariwise you may safely conclude that if it discover not any new instance it is in vain and untrue.[238]

As discussed, the failure to produce new particulars is a sign that inquiry has been diverted from its goal—an axiom which fails to discover *nova* is false. Conversely, the successful production of *nova* does not guarantee the validity of an axiom; rather it signifies only that the direction should be maintained. We can now see the force of the negative instance; when used in a cybernetic epistemology, the negative instance excludes useless pursuits and redirects the inquiry back onto a fruitful course. The

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[236] Bacon, *Novum organum*, in *OFB*, vol. 11, 163–165. 'At in Axiomatibus constituendis per hanc Inductionem, examinatio & probatio etiàm facienda est vtrùm quod constituitur Axioma aptatum sit tantùm, & ad mensuram factum eorum particularium ex quibus extrahitur; an verò sit amplius, & latius. Quòd si sit amplius, aut latius, videndum an eam suam amplitudinem & latitudinem, per nouorum particularium designationem, quasi fide-iussione quâdam firmet; nè vel in iam notis tantùm hæreamus, vel laxiore fortassè complexu, vmbras & formas abstractas, non solida & determinata in materiâ, prensemus.'

[237] My trans., Bacon, *Novum organum*, in *OFB*, vol. 11, 84. 'in omni Axiomate vero constituendo, maior est vis instantiæ negatiuæ.' On Bacon's use of the negative instance see Sessions W.A., "Francis Bacon and the Negative Instance", *Renaissance Papers* (1970) 1–9.

[238] Bacon, *Valerius Terminus*, in *SEH*, vol. 3, 242.

experiments of philosophical mechanics feed back into the inquiry in a continual play of error correction: this is the basis on which I chose the term 'cybernetic epistemology' to characterise Bacon's blending of error correction and truth production. According to Bacon, inquiry fails when men '[...] sever and withdraw their thoughts too soon and too far from experience and particulars [...].'[239] His notion of moving to and fro between generalisations and feedback (experimental testing) means that men's thoughts are never severed from particulars. This is what Bacon intends by the 'closer and purer alliance' of the experimental and the rational faculties.[240] In Baconian inquiry this alliance is achieved via the repeated ascent to axioms (in physics) and descent to experiments (in philosophical mechanics). (See Figure 2).

Bacon's experiment '*touching the making of gold*' in *Sylva sylvarum* illustrates the relationship between physics and philosophical mechanics.[241] On the basis of his inquiry into maturation, Bacon arrives at the following physical 'axioms of maturation':

> The first is, that there be used a temperate heat; for they are ever temperate heats that digest and mature: wherein we mean temperate according to the nature of the subject; for that may be temperate to fruits and liquors, which will not work at all upon metals. The second is, that the spirit of the metal be quickened, and the tangible parts opened: for without those two operations, the spirit of the metal wrought upon will not be able to digest the parts. The third is, that the spirits do spread themselves even, and move not subsultorily; for that will make the parts close and pliant. And this requireth a heat that doth not rise and fall, but continue as equal as may be. The fourth is, that no part of the spirit be emitted, but detained: for if there be emission of spirit, the body of the metal will be hard and churlish. And this will be performed, partly by the temper of the fire, and partly by the closeness of the vessel. The fifth is, that there be choice made of the likeliest and best prepared metal for the version: for that will facilitate the work. The sixth is, that you give time enough for the work; not to prolong hopes (as the alchemists do), but indeed to give nature a convenient space to work in.[242]

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[239] Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 361, cf. vol. 1, 566. 'Radix autem mali hujus, ut et omnium, ea est; quod homines et propere nimis, et nimis longe, ab experientia et rebus particularibus cogitationes suas divellere et abstrahere consueverunt, et suis meditationibus et argumentationibus se totos dedere.'

[240] Bacon, *Novum organum*, in *OFB*, vol. 11, 153.

[241] See Bacon, *Sylva sylvarum*, in *SEH*, vol. 2, 448–450 (italics in original).

[242] Bacon, *Sylva sylvarum*, in *SEH*, vol. 2, 449–450. On Bacon's concept of *spiritus* see Weeks S., "Francis Bacon and the Art-Nature Distinction"; Rees G., especially *OFB*, vol. 6, lix–lxv; Walker D.P., "Francis Bacon and *Spiritus*", in A.G. Debus (ed.),

He then proceeds (out of these physical axioms and his knowledge of the latent schematisms of metals) to derive 'a trial touching the maturing of metals, and thereby turning some of them into gold.'[243] The following trial belongs to philosophical mechanics:

> Let there be a small furnace made, of a temperate heat; let the heat be such as may keep the metal perpetually molten, and no more; for that above all importeth to the work. For the material, take silver, which is the metal that in nature symbolizeth most with gold; put in also with the silver, a tenth part of quicksilver, and a twelfth part of nitre, by weight; both these to quicken and open the body of the metal; and so let the work be continued by the space of six months at the least. I wish also, that there be at some times an injection of some oiled substance; such as they use in the recovering of gold, which by vexing with separations hath been made churlish; and this is to lay the parts more close and smooth, which is the main work. For gold (as we see) is the closest (and therefore the heaviest) of metals; and is likewise the most flexible and tensible. Note, that to think to make gold of quicksilver, because it is the heaviest, is a thing not to be hoped; for quicksilver will not endure the manage of the fire. Next to silver, I think copper were fittest to be the material.[244]

The above experiment illustrates the narrow scope of physical axioms and the limitations of the corresponding mechanical rules of transformation. When it comes to making gold, the mechanic is confined to specific ways and means of operating. Although it may be possible to transmute a wide range of bodies into gold, and although there may be many possible modes of operating, these are beyond his reach. His choice of material is limited: he is confined to using a material similar to gold, namely, silver or possibly copper. Likewise, his mode of operation is confined to imitating the latent process whereby gold is naturally produced. Consequently, philosophical mechanics 'extends and enlarges operation beyond the ones usually found in nature to certain operations which are closer to hand or not very far off.'[245] Because the axioms of physics are tied to concrete bodies, the mechanic is 'tied in operation, either to the basis of the matter or to the condition of the

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Science, Medicine, and Society in the Renaissance: Essays to Honour Walter Pagel (New York: 1972) 121–130; idem, "Spirits in Francis Bacon", in Fattori M. (ed.), *Francis Bacon: terminologia e fortuna nel XVII secolo* (Rome: 1984) 315–327.

[243] Bacon, *Sylva sylvarum*, in *SEH*, vol. 2, 449.

[244] Bacon, *Sylva sylvarum*, in *SEH*, vol. 2, 450.

[245] Bacon, *Novum organum*, in *OFB*, vol. 11, 209: 'operationem extendit & promouet, ab ijs quæ ordinariò in Naturâ inueniuntur, ad quædam proxima, aut à proximis non admodùm remota.'

efficient.'[246] Mechanics has relatively slight powers to alter embodied structures; it merely imitates the productions of nature free. As Bacon puts it, 'Physic carries men in narrow and restrained ways, imitating the ordinary flexuous courses of Nature.'[247] In the *Advancement of learning* he explains:

> by the knowledge of Phisicall causes, there cannot faile to followe, many indications and designations of new particulers, if men in their speculation will keepe one eye vpon vse & practise. But these are but Coastings along the shoare, *Premendo littus iniquum*, For it seemeth to me, there can hardly bee discouered any radicall or fundamentall alterations, and innouations in Nature, either by the fortune & essayes of experiments, or by the light and direction of Phisical causes.[248]

Although knowledge of physical causes will discover new particulars, these will be imitations, not unparalleled inventions.

By clarifying the role of philosophical mechanics in Baconian inquiry, we can also throw light on the different roles played by imitations of nature and unparalleled inventions in Bacon's Instauration. Peter Zetterberg argues that, for Bacon, 'science in its theory and art in its work should reflect or echo or imitate nature.'[249] He cites the many examples of imitation in Bacon's *New Atlantis*:

> In Salomon's House they have perfected "the imitation of natural mines; and the producing also of new artificial metals." They have "a number of artificial wells and fountains, made in imitation of the natural sources and baths." They have "great and spacious houses, where they imitate and demonstrate meteors; as snow, hail, rain, some artificial rains of bodies and not of water, thunders, lightnings." They have "heats in imitation of the sun's and heavenly bodies heats." They have "perfume houses; wherewith

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246 Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 362, cf. vol. 1, 568: 'inter operandum restringitur et alligatur vel ad *Materiæ Basim*, vel ad *Conditionem Efficientis*' (italics in original).

247 Bacon, *De augmentis scientiarum*, in *SEH*, vol. 4, 362, cf. vol. 1, 568. 'Nam Physica per angustos et impeditos calles humanam operam dirigit, naturæ ordinariæ flexuosos tramites imitata.'

248 Bacon, *Advancement of learning*, in *OFB*, vol. 4, 89. As M. Kiernan notes, the reference ('Premendo littus iniquum') is Horace, *Odes*, II, x, 3 (see *OFB*, vol. 4, 284). The passage states: 'You will take a straight course, Licinius, / If you are not always thrusting over the deep sea, / or cautiously hugging the dangerous shore too close, / shivering at the prospect of squalls' (trans. D. West). In the final stanza of this Ode, Licinius is advised to act courageously and not run for the coast. This calls to mind the image of the ship on the engraved title of *Instauratio magna* sailing beyond the Pillars of Hercules.

249 Zetterberg P.J., "Echoes of Nature in Salomon's House", *Journal of the History of Ideas* 43, 2 (1982) 179–193, on 180.

> they join also practices of taste. They multiply smells, which may seem strange. They imitate smells." They have "perspective-houses, where they make demonstrations of all lights and radiations." They "make artificial rainbows, haloes, and circles about light." They "represent and imitate all articulate sounds and letters, and the voices and notes of beasts and birds." They have "engine houses, where [...] they imitate and practice to make swift motions." They "imitate also flights of birds." Lastly, they "imitate also motions of living creatures, by images of men, beasts, birds, fishes, and serpents."[250]

Similarly, William Newman (following Pérez-Ramos) argues that producing such imitations as the artificial rainbow and artificial gold 'is the foundation of Bacon's famous maker's knowledge, for it is the identity of the natural and the artificial product that allows man to certify his knowledge of the former's causes by creating the latter.'[251] Although this statement holds true for Bacon's philosophical mechanics, it does not hold true at the higher level of metaphysics and magic. Imitations mark a phase of Baconian inquiry, namely, the experimental testing of physical axioms. This is not the end of Baconian inquiry. Whereas mechanics generates imitations, magic generates unparalleled inventions. In the *New Atlantis* the above imitations are described as 'the preparations and instruments we have for our works.'[252] With regard to magical works, we are simply told that these 'excellent works [...] since you have not seen, it were too long to make descriptions of them; and besides, in the right understanding of those descriptions you might easily err.'[253] The Baconian magus (unlike the mechanic) is empowered to produce and uncover 'things that have never been done before, things of the kind which neither the vicissitudes of nature, nor hard experimenting, nor pure accident could ever have actualised, or human thought dreamed of.'[254] Baconian operation is invariably aimed at widening the scope or latitude of axioms and their corresponding operative precepts. Bacon

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[250] Bacon, *New Atlantis*, in *SEH*, vol. 3, 156–164, quoted in Zetterberg P.J., "Echoes of Nature in Salomon's House" 187.

[251] Newman W.R., *Promethean Ambitions: Alchemy and the Quest to Perfect Nature* (Chicago: 2004) 261. See also Llasera M., "Art, Artifice and the Artificial in the Works of Bacon", *Bulletin de la societe d'etudes Anglo-Americaines des XVII^e et XVIII^e siecles* 22 (1986) 7–18.

[252] Bacon, *New Atlantis*, in *SEH*, vol. 3, 156.

[253] Bacon, *New Atlantis*, in *SEH*, vol. 3, 166.

[254] Bacon, *Novum organum*, in *OFB*, vol. 11, 203. 'Itaque quæ adhuc facta non sunt, qualia nec Naturæ vicissitudines, neque Experimentales industriæ, neque Casus ipse, in Actum vnquàm perduxissent, neque cogitationem humanam subitura fuissent, detegere & producere potest.'

believed knowledge of forms (metaphysical axioms) would 'enfranchise the power of Man vnto the greatest libertie, and possibilitie of workes and effects.'[255] Philosophical mechanics cements the union between *res* and *mens* in the ascent to axioms of the widest latitude (forms).

6. *Conclusion*

In the preface to *Scala intellectus* Bacon vividly portrays his way of inquiry in striking geographical metaphors.[256] The journey begins in 'the woods of nature, both obscured and darkened by an infinite variety of experiments as though by foliage, and entangled by the subtlety of observations as though by undergrowth and brambles.'[257] The wood (*sylva*) is Bacon's figure for the primary history prior to its organisation in tables (*experientia literata*) which allows inquiry to 'penetrate and pass by' nature's subtleties.[258] Eventually, Bacon says, we emerge from the woodland and 'come to matters perhaps more open but yet more arduous […] to the base of the mountains.'[259] At this point the ascent to axioms (interpretation of nature) begins. His description of this final phase of inquiry is worth quoting in full:

> He who endures with true and unflagging patience to suspend judgement and gradually to ascend and surmount the ridges of things, as though of mountains, first one and then another and then again another, will reach betimes the summits and peaks of nature where there is both a serene stopping place and a most lovely view out over things, and a descent by a gentle slope leading to all practical things.[260]

As described in figure 2, interpretation repeatedly ascends to axioms and descends to experiments. But each ascent reaches higher, to a more

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[255] Bacon, *Advancement of learning*, in *OFB*, vol. 4, 85.

[256] Bacon, *Scala intellectus*, in *SEH*, vol. 2, 687–689.

[257] My trans., Bacon, *Scala intellectus*, in *SEH*, vol. 2, 688–689: 'in quo certe sylvas naturæ, et variatione infinita experimentorum veluti foliis opacas et obscuras, et observationum subtilitate veluti virgultis et vepribus implicatas, penetravimus et præterivimus.'

[258] My trans., Bacon, *Scala intellectus*, in *SEH*, vol. 2, 689.

[259] My trans., Bacon, *Scala intellectus*, in *SEH*, vol. 2, 689. 'Atque nunc ad magis aperta fortasse sed tamen ad magis ardua pervenimus, ex sylvis scilicet ad radices montium.'

[260] My trans., Bacon, *Scala intellectus*, in *SEH*, vol. 2, 689. 'Qui autem judicium cohibere, et gradatim adscendere, et rerum veluti montium juga, unum primo, deinde alterum ac rursus alterum, superare, cum patientia vera et indefessa sustinuerit; ille ad summitates et vertices naturæ mature perveniet, ubi et statio serena et pulcherrimus rerum prospectus et descensus molli clivo ducens ad omnes practicas.'

general axiom, until interpretation finally arrives at knowledge of forms ('the summits and peaks of nature'). From there the science of magic descends 'by a gentle slope' to the *magnalia* of nature (unparalleled works). Bacon commentary has been perfunctory in fleshing out the details of this journey. I have attempted, by focusing on the relationship between mechanics and experiment, to delineate the structural components of inquiry and to substantially gloss Bacon's vivid depiction of the inquisitional ascent.

The three distinct phases of mechanics—mechanical history, *experientia literata* and philosophical mechanics—are correlated with a meticulously graduated scheme of experiment. As we have seen, even the works (*opera*) of philosophical mechanics (which corresponds to Bacon's *scientia* of physics) are no more than imitations of nature. But the goal of Baconian inquiry is unparalleled works, and these are derived systematically on the basis of knowledge of forms. As Bacon puts it, 'all greater power depends on and is systematically derived from the well-springs of forms.'[261] Each type of mechanics works to advance inquiry for the purpose of discovering forms. The aim of Baconian knowledge is to discover forms, and the aim of Baconian power ('true natural magic') is to produce unparalleled works.[262] Terms such as 'maker's knowledge' purport to encapsulate the Baconian relationship between truth and utility. As stated in the Introduction, Pérez-Ramos speaks of 'an intimate relationship between objects of cognition and objects of construction' where 'knowing' is 'a kind of making.'[263] More recently, Pamela Smith has dubbed this hybrid procedure 'artisanal epistemology.'[264] This phrase is opaque when used as a generic description of Baconian inquiry because knowledge and operation come into play in various ways at different stages in inquiry. Whilst it is correct to say that there is 'an intimate relationship' between knowing and making, this relationship requires precise delineation.

[261] Bacon, *Novum organum*, in *OFB*, vol. 11, 303: 'atque omnem potentiam maiorem pendere & ordine deriuari à fontibus Formarum, quarum nulla adhuc inuenta est.'

[262] In *De augmentis scientiarum*, Bacon defines magic as: 'the science which applies the knowledge of hidden forms to the production of wonderful operations; and by uniting (as they say) actives with passives, displays the wonderful works of nature' [scientia quæ cognitionem *Formarum Abditarum* ad opera admiranda deducat; atque, quod dici solet, *activa cum passivis conjungendo* magnalia naturæ manifestet] (*SEH*, vol. 4, 366–367, cf. vol. 1, 573, italics in original).

[263] Pérez-Ramos A., *Francis Bacon's Idea of Science* 48.

[264] Smith P.H., *The Body of the Artisan* 59–93.

The final goal of Baconian inquiry is utility, the powerful productive capacity of Baconian magic. On the issue of truth versus utility, Rossi defends Bacon against charges of 'vulgar utilitarianism.'[265] Rossi succeeds in demonstrating how truth for Bacon terminates in knowledge of *ipsissimæ res* (forms).[266] However, he misleadingly intimates that truth is the terminus of Bacon's programme. Although Rossi highlights the influence of magical and alchemical traditions on Bacon, he is reluctant to identify Bacon's goals with the utilitarian goals of natural magic. Rossi (following Pérez-Ramos) insists that 'Bacon's science is directed toward *opera* not in the sense of making artefacts, but in searching for "Nature's *effects*, phenomena such as heat, colour, or motion."'[267] This interpretation terminates the Baconian project at the discovery of forms and transforms Bacon's science of magic into something approximating modern notions of pure science. This shift in emphasis towards more cognitive goals overshadows and attenuates the unquestionable utilitarian motives of Bacon's programme. Both Rossi and Pérez-Ramos fail to distinguish between the *inquisitional* role for *opera* leading to discovery of forms, and the *programmatic* aim of producing unparalleled *opera* via the science of magic.

The sole function of intermediate *opera* (produced by all three kinds of mechanics) is inquisitional, but the goal of Bacon's Instauration is unparalleled works (the fruits of natural magic). During inquiry, as Rossi rightly argues, Bacon is uninterested in utility, and the production of works is solely for the purpose of furthering inquiry. At the level of philosophical mechanics, *opera* function as his criterion of truth: they set the seal on inquiry and control unwarranted speculation. In this way, as Bacon aptly puts it, 'the art of discovering will grow as the number of things discovered grows.'[268] However, the purpose of inquiry is not truth *per se* but the production of all things possible. For Bacon, the separation of truth and utility is unthinkable because both are educed only through an experimental engagement with matter.

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[265] Rossi P., *Philosophy, Technology, and the Arts* 150; citing J. von Liebig, *Über F. Bacon von Verulam und die Methode der Naturforschung* (Munich: 1863) 105, 118.

[266] See Rossi P., *Philosophy, Technology, and the Arts* 157–160. See Bacon, *Novum organum*, in *OFB*, vol. 1, 186.

[267] Rossi P., "Bacon's Idea of Science" 38, quoting Pérez-Ramos A., *Francis Bacon's Idea of Science* 142 (italics in original).

[268] Bacon, *Novum organum*, in *OFB*, vol. 11, 196. 'Artem Inueniendi cum Inuentis adolescere posse.'

To conclude, I maintain that mechanics and its works are a *means* contributing to the discovery of forms. This explanation of mechanics clarifies Bacon's prioritisation of non-utilitarian light-bearing experiments. But the terminus, the *end*, of Baconian inquiry, is the systematic production of magical works (fruit-bearing experiments). Consequently, Bacon excludes from the category of magical works those produced by mechanics: were such works included, knowledge of forms would be redundant. The fruits of Baconian natural magic (based on knowledge of forms) will be beyond our wildest dreams. The unique terminus of Bacon's 'Great Instauration' is the transformation of the current realm of nature into an alternative universe tailored to human requirements.[269]

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BACON'S BROTHERHOOD AND ITS CLASSICAL SOURCES: PRODUCING AND COMMUNICATING KNOWLEDGE IN THE PROJECT OF THE GREAT INSTAURATION

Dana Jalobeanu

The Brotherhood of Light: Solomon's House

In *New Atlantis*, Bacon pictures a whole society centered upon a strange institution which captured many imaginations ever since the first publication of the allegedly unfinished writing, in 1626. Some saw it as utopian fiction, others, as a practical project for a future scientific society, some read it as a part of Bacon's *Instauratio Magna*, others as a literary or theatrical device.[1] There were many divergent interpretations of New Atlantis in the seventeenth century as well. Robert Burton described

[1] Some such recent and less recent examples are Weinberger J., "Science and Rule in Bacon's Utopia: An Introduction to the Reading of New Atlantis", *The American Political Science Review* 70 (1976) 865–885, for the "utopian" interpretation claiming that what we have in *New Atlantis* is a rewriting of the old genre of utopia in the vein of modernity. See also Weinberger J., *Science, Faith and Politics: Francis Bacon and the Utopian Roots of Modern Age* (Cornell: 1985). For a reinterpretation of the same utopian vein, but seeing *New Atlantis* as a negative form of utopia see Spitz D., "Bacon's New Atlantis: A Reinterpretation", *Midwest Journal of Political Science* 4 (1960) 52–61. Another important trend of interpretation comes from cultural studies and the discussions upon the rhetoric and politics of early modern science. See, for example, Albanese D., "New Atlantis and the uses of Utopia", *ELH* 57 (1990) 503–528, or Aughterson K., "The Waking Vision: Reference in *New Atlantis*", *Renaissance Quarterly* 45 (1992) 119–139. Solomon's house has also been considered a project of a future scientific society, see Farrington B., *Francis Bacon: Philosopher of the Industrial Science* (New York: 1949), or as a (possibly non-intentional) model for the Royal Society. See also Lynch W.T., *Solomon's Child: Method in Early Royal Society London* (New York: 2001). More recently, the emphasis of the interpretation shifted from scientific or political features towards modes of expression and the construction of discourse. Brownen Price has discussed the ways of disclosing the secret as expressing Bacon's views on the general importance of secrets in the new science, Sarah Hutton pointed towards the intrinsic paradoxical character of *New Atlantis* and to its careful rhetoric destined to enlist the readers among the researchers of Nature's secrets, while Donna Coffey has pointed out several similitudes between Bacon's *New Atlantis* and Jacobean court masques. See Price, B. (ed), *New Atlantis: New Interdisciplinary Essays* (Manchester: 2001), Hutton S., "Persuasions to science: Baconian rhetoric and the New Atlantis" in Price B. (ed.), *New Atlantis* 48–59, Coffey D., "As in a theatre: scientific spectacle in Bacon's *New Atlantis*", *Science as Culture* 13 (2004) 259–290.

it as a utopian commonwealth,[2] while various members of the Early Royal Society have been arguing that Solomon House was, in fact, an appropriate model for a collective enterprise designed to produce useful knowledge. Joseph Glanvill, following Thomas Sprat, claimed that in *New Atlantis*, Bacon 'desired and formed a Society of Experiments in a Romantick Model; but could do no more: his time was not ripe for such performances',[3] while John Evelyn read it as exactly the kind of practical model that the new science is in need for.[4]

One reason for so many divergent interpretations is that *New Atlantis* stands at odds with other writings of Francis Bacon: it is a literary fiction.[5] Another might be simply that in reading New Atlantis one gets the strong feeling that nothing is quite what it is supposed to be.[6] Here are just some of the most striking examples: the people of Bensalem are Christians, but they have received Revelation in a very special way, through a direct miracle which was nevertheless accessible only

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[2] Robert Burton, *Anatomy of Melancholy* (London: 1661) 60. 'I will yet to satisfy and please myself, make an Utopia of mine owne, a new Atlantis, a poeticall Commonwealth of mine owne, in which I will freely domineere, build cities, make statuse, as I lift myselfe', and also: 'Utopian parity is a kind of government to be whished for, rather than effected, *Respublica Christianopolitana, Campanella*'s city of the Sun, and that new *Atlantis*, witty fictions, but meer Chimera's and Plato's community in many things is impious, absurd and ridiculous', Robert Burton, *Anatomy of Melancholy* 63.

[3] Joseph Glanvill, *Plus ultra* (London: 1668) 88.

[4] John Evelyn, *Introductions Concerning Erecting a Library* (London: 1661), cited by Foster J.R., *Ancients and Moderns: A Study of the Rise of the Scientific Movement in 17th century England* (Dover: 1982) 317.

[5] As it was emphasized time and again, *New Atlantis* is the only fiction written by Bacon, an author who often criticised the use of 'fictions' in reconstructing natural philosophy. And however, *New Atlantis* was rarely read as a fiction and more often considered to be a project for a future scientific society. See Hutton S. "Persuasions to science". Moreover, it is probably Bacon's only writing which, although talking about natural and experimental knowledge and a reformation of the human being, does not belong, at least not by design, to the general plan of the *Great Instauration*.

[6] For a way in which such a suggestion might be transformed into a work hypothesis for a general interpretation of *New Atlantis* see Spitz D., "Bacon's New Atlantis: A Reinterpretaton, *Midwest Journal of Political Science* 4 (1960) 52–61. Spitz's direction of reading suggest that all the characters of *New Atlantis* are wearing all sorts of masks (i.e. Joabin the Jew is a Socratic figure in disguise, one of the Wise Brothers of Solomon's house etc.) destined to hide a dark side of Bensalem and a rather dangerous attempt of Bacon to prove that philosophy is 'superior' to religion. There is another direction of interpretation of *New Atlantis* as a literary device using some of the techniques of the court masques to re-create a sort of theatrical discourse about the new science that will encourage the reader to be willing to take part in the new enterprise. See Coffey D., "As is a theatre".

to the learned fraternity of Solomon's House.[7] They had miraculously received not only the canonical books of the Bible but some of the lost ones, too.[8] They speak lots of languages, from Chaldean to Persian and from Hebrew to Latin, but the conversation with the sailors takes place in Spanish, meaning the language of the 'traditional enemy'.[9] The Bensalemians seem to live a happy and virtuous life, according to nature, under the rule of the wise; however, the very status of their rulers is rather mysterious, as it is the relation between the House of Solomon, the people and an invisible king.[10] The fabulous and well guarded secrets of Solomon's House are only in part the result of an organized activity of producing knowledge. Otherwise they are the result of a careful preservation of ancient knowledge originated in the 'old' Atlantis and numerous and carefully staged espionage expeditions throughout Europe.[11] Moreover, as has been emphasized, the

[7] *New Atlantis* (1626), Francis Bacon, *Collected Works*, Speding J. – Heath D. – Ellis R.L. (eds.) 14 vols. (New York: 1858–1874), vol. 12, 137–138. I will quote this edition as WFB followed by the number of the volume and the page (*WFB* III 137–138). Occasionally I will also quote the new edition of complete works made by Graham Rees, *Oxford Francis Bacon*, as OFB followed by the volume number and page.

[8] The revelation is received through a miraculous sign on the sky and the discovery of an arch on the sea. In the arch there is a trunk containing the Scriptures and a letter certifying the texts. The letter is said to be from one of the apostles, Bartholomew. It is a very peculiar way of receiving revelation, as it was often discussed. See Renaker D., "A miracle of engineering: The conversion of Bensalem in Bacon's *New Atlantis*", *Studies in Philology* 87 (1990) 181–194. In the Christian tradition, there is such an apostle, Bartholomew, who is mentioned in the tradition of the Christ Fathers as travelling to the East. In the tradition of the apocryphal Scriptures there is a Gospel after Bartholomew, one of the Gospels mentioned by Jerome, together with the Gospel of Thomas, the Egyptian Gospels and others.

[9] Not only that Spain had a very bad press around 1625, in England, but Bacon himself wrote a small treatise arguing in favor of the opportunity of a war with Spain around the same time with the composition of *New Atlantis*. Francis Bacon, *Considerations touching upon the War with Spain*, ed. William Rawley, *Certaine Miscellany Works of Francis Bacon* (London: 1629).

[10] The strangeness of the social and political relations in *New Atlantis* is such that numerous interpretations suggested that Bacon is either criticising the political setting of England of his time (including his king) or that in picturing Bensalem he was using large doses of irony to show us an impossible world where dark secrets are hidden. For the first direction of interpretation see Kendrick C., "The imperial laboratory: discovering forms in *New Atlantis*" *ELH* 70 (2003) 1021–1042, for the second Spitz D., "Bacon's *New Atlantis*: A Reinterpretation".

[11] 'We have twelf that sail in foreign countries, under the names of other nations (for our own we conceal) who brings us the books and abstracts and patterns of experiments of all other parts. These we call merchants of lights', *WFB* vol. III 164. The whole enterprise of the House of Solomon is described as a 'trade of light'. *WFB* vol. III 147.

list of experiments and discoveries associated with Solomon's House contains very few, if any, new scientific knowledge.[12] They rather look like a catalogue of topics dear to any Renaissance philosopher: transmutation, flying machines, natural selection, prodigies and wonders and prolongation of life. As for the Solomon's House itself, it is highly structured, hierarchical and extremely protective of its "secrets". On the other hand, the whole story is nothing else but a progressive disclosure of secrets, culminating with an exposition of procedures, structure and functioning of Solomon's House. Nevertheless, unlike in other stories of a 'secret society revealing itself' – a kind of narrative very popular in the sixteenth and seventeenth-century – the meaning of such communication is far from clear. What would be the reaction of the outside world in hearing about the perfect or the happy society of Bensalem?[13] In other words, what is the intended message for the reader? Are we given an example of a good society, a model of *doing* science, a desirable political order, an ideal of social life or a model of virtue?

In this paper I will address some of the previous questions; starting from the perspective of a seventeenth century reader and trying to provide some of the background against which Bacon's *audience* would have read *New Atlantis.* I will argue that there is such a 'lost background'; that *New Atlantis* was not an independent piece of writing in itself, but a part of a larger project destined to popularize and communicate the 'new' philosophy. I will explore some of this lost background and argue that one of its possible sources might be found in Seneca's writings, especially in the *Epistles* and *Natural Questions*. I will show that, if read against this background, some of the paradoxical character of *New Atlantis* simply disappear, while other, more interesting questions, emerge.

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[12] Rosalie Colie has argued convincingly that quite a number of the devices and 'discoveries' presented in *New Atlantis* represent, in fact, descriptions of Drebbel's or Salomon de Caus's discoveries and "machines", presented at the Jacobean court. Colie R., "Cornelis Drebbel and Salomon de Caus: two Jacobean models for Salomon's House", *Huntington Library Quarterly* 18 (1954) 245–260.

[13] Especially in the light of an early reference those few who, returning from Bensalem, told their stories which were taken as mere phantesies and dreams when heard back in Europe. 'What those few that returned may have reported abroad I know not. But you must think, whatsoever they have said could be taken where they came but for a dream.' *WFB* vol. III 145.

Secrets, Knowledge and Natural Magic: The Presentation of New Atlantis and its Seventeenth Century Readers

On its title page, *New Atlantis* is introduced to its readers as an unfinished piece of work. This is by no means unusual for Bacon's writings. Indeed, with very few exceptions, none of his works was ever presented as finished.[14] On the other hand, *New Atlantis* was published as the second part of a larger book: *Sylva Sylvarum.*[15] The first readers of *New Atlantis* were therefore confronted with a book of a peculiar character: a sort of natural history, supplemented by an 'unfinished fable' (as *New Atlantis* was labelled by Rawley in the preface). Unlike other posthumous works published by William Rawley, this one is presented as having a sort of unity.[16]

Sylva is a sort of catalogue of experiments,[17] a storehouse of facts and observations from various sources, apparently designed for the sake of a future plan of interpreting nature. It is also presented as a work in progress and looks very much like a notebook of experiments, facts

[14] Most of Bacon's prefaces are emphasizing this point, whether it is the case of *The Advancement of Learning, New Organon*, or various histories. Moreover, to some extent, all Bacon's writings were introduced to their readers as mere parts of the grand scale project, and therefore, necessarily incomplete. It has been suggested that Bacon's claims concerning the unfinished status of most of his works were important parts of his general strategy for enrolling his readers as potential future aids in collecting histories, or, at least, as sympathizers of the new way of doing philosphy. Whitney, *Francis Bacon and Modernity* (New Haven: 1986) 189–190.

[15] The books was published posthumously by Rawley, under the title *Sylva Sylvarum or A Natural History in ten centuries*, with *New Atlantis* as the second part of the book. In his preface, Rawley claims that such was the design of Francis Bacon himself. This composite format was preserved for other seventeenth-century editions of *New Atlantis* and *Sylva Sylvarum* and seemed to have been rather popular.

[16] Apart from claiming that this was Bacon's design in publishing the two, Rawley also tells the readers that *New Atlantis* was left unfinished because Bacon wanted to gather together the experiments of *Sylva Sylvarum.* Moreover, *New Atlantis* comes after *Sylva* in virtue of having 'so near an Affinity (in one part of it) with the preceeding Natural history'. *WFB* vol. III 147.

[17] Literally, a 'collection of collections', a form of writing that has become rather popular in England, in the second half of the seventeenth century. However, such a collection of facts, observations of curiosities is of classical origin and represents a form of writing which was revived by the Renaissance. See De Bruyn F., "The Classical Sylva and the development of scientific writing in seventeenth-century England", *New Literary History* 32 (2001) 347–373. There were a couple of important writings in the second half of the century mirroring or continuing Bacon's *Sylva Sylvarum* as has been shown by Rees G., "An unpublished manuscript by Francis Bacon: *Sylva Sylvarum* drafts and other working notes", *Annals of Science* 38 (1981) 377–412.

and ideas to be tried in the future.[18] Meanwhile, it is very different from Bacon's other natural histories. It does not have an obvious subject and the order of experiments and observation is not obvious. It deals with a very large storehouse of facts and phenomena, from the constitution of matter, to perceptions, and the workings of the imagination. The whole last century (chapter) of the book is dealing with producing illusions, manipulating sympathies and antipathies, experiments 'touching the Transmission of Spirits and the force of Imagination'.[19] Bacon himself claims that *Sylva* is a work on natural magic rather than natural philosophy properly speaking.[20] Moreover, *Sylva Sylvarum* does not contain only facts and experiments but also conjectures, list of further questions to be explored, directions of study and even theories. Quite a number of them are reports on second hand sources, most of them unidentified in the text itself.[21]

However, this composite volume was by far the most famous of Bacon's writings in the seventeenth century.[22] And this not only because of the literary qualities or strange paradoxes of the New Atlantis, but for

[18] A misleading first impression, as it was shown by Graham Rees' discovery of a manuscript of *Sylva* showing corrections in Bacon's hands and many traces of editing. The misleading character of *Sylva* is also clear from Rawley's preface which aludes to the 'hidden order' of the work. See Rees G., "An unpublished manuscript by Francis Bacon: *Sylva Sylvarum* drafts and other working notes", *Annals of Science* 38 (1981) 377–412. Bacon has changed the style and the emphasis of *Sylva* by collecting not only facts, observations and experiments, but also hypotheses or even theories, as any cursory reading of *Sylva Sylvarum* might show. Quite a number of his classes of experiments and observations start, as a matter of fact, with a theoretical understructure on which the experiments are constructed. The most striking example is the second century, where one can easily found a theory of sound perceptions and some elements of a theory of music. Rawley's preface points to the fact that *Sylva* contains not only experiments but some 'gloss of the causes', *WFB* vol. II 336. Rees suggestion is that *Sylva* is mainly about causes of natural phenomena and has also an underlying unity provided by Bacon's pneumatic theory of matter. Rees, "An unpublished manuscript by Francis Bacon" 391.

[19] Sylva (1638) 234, *WFB* vol. II 640.

[20] *Sylva*, Century I 93, *WFB* vol. II 378.

[21] As Graham Rees has shown, in most cases this is also part of a strategy; in the manuscript, Bacon crossed out a number of such references and replaced them with 'it has been reported' or other indirect and impersonal verbal constructions. Rees G., "An unpublished manuscript by Francis Bacon" 392–393. In *Sylva*, Bacon reported facts and observations borrowed from a number of sources, mainly Aristotle's *Problems, Mechanica, Meteorologica* and Pliny's *Natural history*, but also Hippocrates, Galen, Plutarch, Cicero and Diogene Laertios, Della Porta, Cardano and others.

[22] It went through more editions than the *Novum Organum* and was one of the main forces behind the spread of Baconianism in the seventeenth century. See Rees G., "An unpublished manuscript of Francis Bacon" 387.

the very observations and experiments recorded in *Sylva Sylvarum*. What looks today as an unreadable heap of observations, mostly gathered from second-hand sources, was the subject of a deep interest and emulation in seventeenth-century natural philosophy. The members of the Royal Society tried the experiments and observations of the *Sylva Sylvarum* and planed to continue the list.[23] A number of works were inspired by *Sylva Sylvarum*,[24] while Solomon's House was considered by many as the institutional device necessary for the completion and implementation of Bacon's grand scheme for a reformation of learning.[25]

This is by all means strange, given the paradoxes and peculiarities of the Brotherhood depicted by Bacon, his insistence on secrets, the rejection of an open and equalitarian scientific enterprise and all the moral, political and religious connotations of *New Atlantis*. In many respects, the kind of enterprise presented in *New Atlantis* is the very opposite to what has been traditionally associated with the 'new science', while the kind of experiments listed in *Sylva Sylvarum* are very far away from what has been generally consider as belonging to the program of the new experimental philosophy.

We are left, then, with some important questions, like, for example, why was the book so popular between the members of the Royal Society. How did they read *New Atlantis* and *Sylva*? In what way was this composite book about natural philosophy read as a program to be continued? Was there a sort of background information lost in between their time and ours which helped them perceived the unity of Bacon's enterprise?

In what follows I will try to provide some of this lost background, still available to Bacon's contemporaries. I will start by showing that Bacon's idea of a Brotherhood of learning, while featuring in early and late writings as well, underwent an interesting transformation during the

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[23] For example, Robert Boyle, in *Certain Physiological Essays*, talks about collecting a whole series of 'particulars' and experimental material in order to write a 'continuation of the Lord Verulam's Sylva Sylvarum, or Natural History'.

[24] For example Robert Austen, *Observations upon some part of Sir Francis Bacon's Natural History* (Oxford: 1658); Joshua Childrey, *Britannia Baconica, or the natural rarities of England, Scotland and Wale* (London: 1660); Thomas Pope Blount, *A natural history containing many not common observations* (London: 1693); Robert Plot, *The Natural history of Stafford-shire* (London: 1686). For a critical appraisal of *Sylva* see Alexander Ross, *Arcana microcosmi* […] *with a refutation of Bacon's Natural History* (London: 1652).

[25] See for example Abraham Cowley's project for the reformation of natural philosophy in Abraham Cowley, *A proposition for the Advancement of Experimental Philosophy* (London: 1661).

last years of the author's life. Especially in Bacon's last writings, such a projected society is focused not so much on the *production* but rather on the *communication of knowledge*. I will then show that around the same time as the composition of *New Atlantis*, Bacon reworked his earlier ideas on communicating knowledge according to the public, as a part of a larger rewriting project, centred upon the idea of a community of learners. I will then suggest that, at least in part, this larger project has striking similarities with an ancient model: Seneca's *Natural Questions*.

The "Brotherhood of Lights" in the Project of the Great Instauration

Bacon's Brotherhood of learning figures already in his early manifesto *The Advancement of Learning* (1605), as a key feature in the reformation of knowledge. In Bacon's view, such a community would be the solution for one of the major deficiencies of knowledge: the isolation of those involved so far in the production of knowledge.[26] However, what looks at the first sight as an argument for a more open, international and communal research is structured instead along the lines of a monastic order, ancient school of philosophy or Renaissance secret society.

> As nature created Brotherhood in Families, and Arts Mechanical contract Brotherhoods in Communalties, and the Anoyntmens of God superinduced a Brotherhood in Kings and Bishops; so in like manner there cannot be but a fraternity in learning and illumination, relating to that paternity which is attributed to God, who is called the Father of Illumination or Lights.[27]

There are a number of interesting features associated with such a Brotherhood: it is 'natural' fraternity of the learned, in search of illumination. Note the reference to God's paternity; it relates with another famous Baconian image: the (chosen) sons of knowledge.[28] As such, the Brother-

[26] 'For as the proficience of learning consisteth much in the orders and institutions of universities in the same states and kingdoms, so it would yet be more advanced, if there were more Intelligence Mutual between the universities of Europe than now there is. We see, there be many Orders and Foundations, which thought they were divided under several sovereignties and territories, yet they take themselves to have a kind of contract, fraternitie and correspondence, one with the other, insomuch as they have Provincials and Generals', *WFB* vol. III 327.

[27] *The Advancement of Learning*, *WFB* vol. III 327.

[28] In numerous writings, Bacon refers to the community of learners as sons of knowledge, or a sort of natural 'family'. In *De augmentis scientiarum*, the reference is

hood seems to be something else than just a new institution for the production of knowledge: it has religious and moral connotations,[29] as well as political implications, since it implies a redistribution of loyalties. In rewriting this passage for the Latin version, *De Augmentis Scientiarum*, Bacon elaborates on the attributes of such a Brotherhood, introducing a new reference to 'vows and regulations', that 'make a brotherhood in religious orders',[30] and to their organization under provincials and generals which are general governors of such an international body.

What would be the intended purpose of such an institution? The Brotherhood responds to a specific deficiency concerning the communication of knowledge and the isolation of the researcher. As a result of this deficiency, the knowledge, instead of increasing, was constantly lost. Now, this is a central idea in all Bacon's writings about the advancement of learning. For example, in *Valerius Terminus*, an unpublished manuscript from the very first years of the seventeenth century, Bacon claims – very uncharacteristically – that we probably know *less* than the ancients, or, at least, we have no idea about the true extent of the ancient knowledge because in the very process of transmitting it, a lot is lost. The main cause of this was the lack of coordination and the improper way of communicating and transmitting knowledge within the same generation of philosophers or through time.[31] Bacon is hinting here to what will become later on a theory on communicating knowledge.[32] The proposed remedy in *Valerius Terminus* is a *council for the administration of knowledge* built upon the model used by the Spanish monarchy in the administration of the Empire.[33] In *The Advancement of Learning* is the projected Brotherhood, a fraternity of the learned men

to the true 'sons of science', *WFB* vol. IV 449. A similar reference can be found in *Temporis Partus Masculus; Fillum labyrinthi* bears a dedication 'ad filios'. For a discussion of Bacon's *oratio ad fillios* see Whitney C., *Francis Bacon and Modernity* 200–207.

[29] As shown by Rose Mary Sargent, Bacon's project for a reformation of learning is in many respects a Humanistic project. Unsurprisingly, its main concerns are moral and religious, and some of them are extended into the sphere of natural philosophy. See Sargent R.M., "Francis Bacon's and the Humanistic aspects of Modernity", *Midwest Studies in Philosophy* 26 (2002) 124–139, 129.

[30] *De Augmentis Scientiarum.*, *WFB* vol. IV 289.

[31] *Valerius Terminus*, *WFB* vol. III 225.

[32] *WFB* vol. III 226.

[33] 'So we see that this note leadeth us to an administration of knowledge in some such order and policy as the king of Spain in regard of his great dominion used in state; who tough he hath particular councils for several countries and affairs, yet hath one council of State or least resort, that received the advertisements and certificates from all the rest'.

across Europe, organized according to the model of a religious order. In the later rewriting of *The Advancement of Learning*, the monastic model is even clearer and Bacon more straightforward about his sources: the organization of the Brotherhood of learning is to be paralleled with that of the Jesuits.[34] Moreover, there is at least a hint to the fact that such a model institution must have political power to realize the grand scale project of the reformation of knowledge. In *The Advancement of Learning* Bacon emphasizes the fact that such a reformation of knowledge is a state business, *opera basilica*. In a splendid exercise of rhetoric, Bacon seeks the support of King James for his project which is that of a mere counsellor or adviser.[35] In the absence of such support, the philosopher is merely that pointing the road to be travelled in the future, 'sowing [...] for future ages the seeds of a pure truth and performing my part towards the commencement of the great undertaking'.[36]

In conclusion, Bacon's idea of a special kind of society for the preservation and administration of knowledge, bound by oath and secrecy, international, organized upon the model of a monastic order is not confined to an unpublished manuscript, to a literary fable or a utopian writing, but seems to be an important part of the general scheme of the great instauration, a part having to do with the *administration of knowledge* and with its *transmission*. It is not a communal enterprise on our sense, not even on the seventeenth-century sense. In fact, the idea of common research teams working along the same project and replicating experiments was born toward the end of the seventeenth century or even

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[34] This is extremely strange at first sight, since it seems to contradict Bacon's own views on religion. However, it is prefectly explainable in terms of Bacon's own theory concerning the dissemination of knowledge. *De Augmentis Scientiarum* is a rewriting of *The Advancement of Learning* for a different cathegory of readers, for the Continent and for an audience with different religious views. As expressed in a letter to James I from October 1623, the rewriting of *The Advancement of Learning* was done for a larger and more diverse auditorium, on the Continent: 'It is a translation, but enlarged almost to a new work. I had good helps for the language. I have been also mine own *Index Expurgatorius* that it may be read in all places. For since my end in putting into Latin was to have it read everywhere, it had been an absurd contradiction to free it in the language and to pen it up in the matter'. *WFB* vol. XIV 436.

[35] Steven Gaukroger interprets the whole *The Advancement of Learning* as being rewritten for the sole purpose of convincing the king. See Gaukroger S., *Francis Bacon and the reformation of Early Modern Philosophy* (Cambridge: 2001). The image of the philosopher as counselor and advisor is a constant of Bacon's writings, and I will discuss it further in the next paragraphs.

[36] *WFB* vol. IV 104.

later.[37] The experiments recorded in the *Philosophical Transactions of the Royal Society* are rarely common or team experiments but the outcome of individual efforts.[38] The factual and experimental exploration of nature was seen as collaborative at another level: the level of organizing discoveries, drawing upon a common body of facts, recording and transmitting further something like a common inheritance. The more so for Bacon, who had in mind rather the collaborative observational effort of many minds at the very bottom level of the enterprise. In Rawley's words, Bacon saw himself as the architect for the new building, and was unhappy to be forced to spend time in gathering the bricks and raw materials for the construction.[39]

There is at least a hint that Bacon was considering the practical side of such a project and this is Commentarius Solutus, a notebook in which Bacon recorded, in 1608, a number of thoughts on various subjects. One was a list of potential people to be contacted and enlisted in such a common – but much more informal – enterprise: he listed Ralegh, Thomas Rusell, the Earl of Northumbeland and Thomas Harriot.[40] Another was a reference to an international character of such an enterprise. And, finally, there is a list of works to be written, or indeed, rewritten in order to sustain such a project. Among them we can find the concern over a rewriting for larger audiences.[41] There

[37] Much has been writen on the subject of experiments and the pre-history of objectivity. See for example Garber D., "Experiment, Community and the Constitution of Nature in Seventeenth Century", *Perspectives on Science* 3 (1995) 173–205.

[38] Moreover, there are no traces of the modern idea of the replicability of experiment at work in the first issues of the *Philosophical transactions*.

[39] See Rawley's preface to the *Sylva Sylvarum* for such a claim, *WFB* vol. II 336. I am following here the direction of interpretation which reads Bacon's last five years' works as a rewriting of his grand scale project with the purpose of addressing a larger audience and enrolling help and support for the future. It is partly the interpretation given by Leary J., *Francis Bacon and the Politics of Science* (Ames, Iowa State University Press: 1994). See also Jardine L. – Stewart A., *Hostage to Fortune. The Troubled life of Francis Bacon* (New York: 1999). For the rewriting of older projects within a larger framework and with a theory of communicating knowledge in the background see Park K., "Bacon's Enchanted Glass", *ISIS* 75 (1984) 290–302.

[40] *Works* vol. IX 63. Besides these rather obvious choices (however, Ralegh and Northumbeland were in the Tower by the time of such a note), Bacon records several possibilities of luring powerful people into the enterprise, like, for example, Richard Bancroft, the Archbishop of Canterbury, 'Seing and trying whether the B. Of Canterb. may not be affected in it, being single and glorious, and beleeving the sense'. Then, Bacon moves to the question "of learned men beyond the seas to be made, and harkening who they be that may be so inclined." *Works* vol. IX 64.

[41] *Works* vol. IX 64–65. Spedding believed that it is a description of Redargutio Philosophiarum and the project is to recast some of his opinions into a more popular form.

are also various practical notes concerning the project: finding a building, paying people for the compilation of the History of mechanics, drawing a list of instruments and technical devices necessary for further advancements of natural philosophy. Thy are followed by a list of interesting questions concerning future regulations of something akin to a Brotherhood of natural philosophers.

> **Qu.** Of the Order and Discipline, to be mixt with some points popular to invite many to contribute and joyne.
> **Qu.** Of the rules and prescripts of their studies and inquiries
> Allowance for travailing. Allowance for experiments. Intelligence and correspondence with the universities abroad.
> **Qu** of the Manner and praescripts touching Secrecy, tradition and publication.

The project seems to have been abandoned. Or, as it is the case with Bacon's projects, it seemed to have been rewritten in a rather different form (like New Atlantis, for example).[42]

Rewriting and Refashioning the Great Instauration in 1622–1626

During the last five years of his life Bacon was actively engaged in a project of refashioning and rewriting some of his earlier ideas within a larger context and with a purpose of writing for posterity.[43] It was not

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[42] It has been noticed more than once that Bacon's went at great length to rewrite his project several times during his lifetime. Such a habit was well documented in Bacon's own time by Rawley's testimony as well as others. Speding considers that such a constant rewriting is one of Bacon's peculiarities, explicable through his general dissatisfaction with the response to his works. However this may be, the character of rewritten works is more or less obvious for Bacon's late works. *New Atlantis*, especially, has been seen as a 'propaganda for refashioning intellectual production', Kendrik C., "The Imperial Laboratory: Discovering Forms in the *New Atlantis, ELH* 79 (2003) 1021–42, 1021.

[43] Jardine and Stewart are strongly emphasizing the importance of this last five years in Bacon's life. In this interpretation, Bacon's program of the *Great Instauration* as we know it today is, almost in its entirety refashioned in this *quinquenium*. As a result: "Bacon turned the sentence into the cornerstone for intellectual work he wanted to do for the past thirty years. Forced into seclusion, he at last found time to focus his attention on the intellectual projects from which his public commitments had previously distracted him. The philosopher and scientist Francis Bacon who has come down to the twentieth century was the direct result of his infamous political disgrace." Jardine L. – Stewart A., *Hostage to Fortune* 473.

only a process of rewriting,[44] revision,[45] translation and publication[46] but a more complex attempt of re-fashioning bits and pieces of the grand scale project of *Great Instauration* and the image of its author. Bacon is re-working earlier ideas, augmenting some parts of the *Great Instauration*, like the introductory *The Advancement of Learning*, while publishing also a number of natural histories, supervising the Latin translations of a number of works, writing history properly speaking and planning a reformation of English Law. This is the context in which *New Atlantis* was born. The 1625 edition of the *Essays*, published under the name *Counsels Civil and Moral* is refashioned to look more like its model: Seneca's *Epistles.*[47] The opening essay, *Of Truth* addresses the same questions of searching, knowing and illumination under the guidance of God, the Father of light and inspirer of "his chosen".[48] Also, in a couple of letters Bacon pictures himself as an ancient philosopher withdrawn from

[44] Bacon rewrote *The Advancement of Learning* into *De Augmentis Scientiarum* and the Essays, which are augmented and also translated into Latin.

[45] Mainly the Essays, for the third edition published under the title *Counsels Civil and Moral*, introduced by a dedicatory letter to Buckingham where Bacon claims he has enhanced the old edition and the result is an entirely new work. There is also a revision of *De Sapientia Veterum*. According to Rawley's life of Bacon, many more works are revised for publication, including *New Atlantis* and its Latin translation. See *WFB* vol. I 11.

[46] As the project of publishing a natural history every six months which didn't last longer than 1623. However, Bacon did publish two natural histories, *Historia ventorum* and *Historia vitae et mortis* and wrote a couple more. Rawley, in his *Life of Bacon* quotes another two as finished and a couple of more as unfinished. See *WFB* vol. I 11.

[47] There is an interesting manuscript where Bacon claims Seneca's *Epistles* as his model in writing the *Essays.* It is a projected dedicatory letter of the second edition of the *Essays*, of 1612, dedicated to Prince Henry but never published. There, Bacon states: 'To write just treatises requireth leasure in the Writer, and leasure in the Reader, and therefore are not so fitt, neither in regard of your Highness princely affairs, nor in regard of my continuall Services, which is the cause that hath made me chuse to write certaine brief notes, sett downe rather significantlye, then curiously, which I have called Essaies. The word is late, but the thing is ancient. For Seneca's Epistles to Lucillius, if you make them well, are but Essaies – That is, dispersed Meditacions, though conveyed int he worm of Epistles'; Francis Bacon, *The Essayes or Counsel Civill and Moral*, ed. M. Kiernan (Oxford: 1995) 317. For an interpretation of Bacon's *Essays* as build upon a Senecan's model see Sessions W., *Francis Bacon revisited* (New York: 1996) 23–31.

[48] 'yet truch, which only doth judge itself, teacheth that the inquiry of truth, which is the love-making or wooing of it, the knowledge of truth, which is the presence of it, and the belief of truth, which is the enjoying of it, is the sovereign good of human nature. The first creature of God, in the works of the days, was the light of the sense; the last was the light of reason; and his sabbath work ever since, is the illumination of his Spirit. First he breadeth light into the face of man; and still he breadeth and inspireth light into the face of his chosen.' *WFB* vol. VI 378.

the public life into a life of work and contemplation.[49] In others, he is attempting to enlist help for the realization of his projects; this time he is in search not of patronage, but of active collaboration.[50] A couple of writings of the period might be seen as attempting to popularize his view and enlist either present help or enthusiasm for the future. Such is, for example, the Latin version of *The Advancement of Learning*, published under the name *De Augmentis Scientiarum* and introduced as a work for posterity.[51]

As for the process of refashioning his own image, Bacon's favourite models seem to have been Cicero and Seneca. Such is the letter to James I, from 1621, where Bacon compares himself with the great men of the past who had fallen into disgrace: Demosthene, Cicero, Seneca. Another interesting letter is the one written to Lancelot Andrewes in 1622, published by Rawley as an epistle dedicatory to another interesting and unfinished work *A Dialogue touching the Holy War.*[52] In it, Bacon draws on the Stoic literature of consolation and pictures himself as involved in a very important project of reforming both the morals and natural philosophy.[53] The latter, especially, Bacon claims, is in need of rewriting, since it might be the case that what he wrote so far 'flies too high over men's heads'. 'I have a purpose therefore' – Bacon writes, 'to draw it down to the sense, by some pattern of a Natural Story or Inquisition.'[54] Such a revision is directed to make the general purpose of the grand scale project more accessible to the public but also to enlist

[49] Letter to James I, July, 1621, *WFB* vol. VII 296–7, Letter to Lancelot Andrewes, 1622, *WFB* vol. VII 371–4.

[50] Letter to Father Redemptus Barazan, 1623, *WFB* vol. XIV 375–377; Letter to Father Fulgentio, 1625. See Leary, *Francis Bacon and the Politics of Science*, 66–68.

[51] In the letter to Prince Charles upon the presentation of *De Augmentis Scientiarum* Bacon wrote, for example: 'It is a book I think will live, and be a citizen of the world, as English books are not', *WFB* vol. XIV 436.

[52] Published by Rawley in 1629, the *Dialogue* opens with this dedicatory letter in which Bacon pictures his period of disgrace as one simlar with the Fate of Seneca, Demosthene and Cicero. The letter is explicitly constructed as a writing of consolation and praises Seneca's years of exile: 'Seneca indeed, who was condemned for many Corruptions and Crimes, and banished into a solitary Island, kept a mean: For, though his Pen did not freeze, yet he abtained from intruding into matters of businesse; but spent his time in writing Books of excellent Argument and Use, for All Ages', *WFB* vol. XIV 371.

[53] He mentions various moral and political writings, as one directed to a reformation of law, only to move on to explaining his preocupations for the rewriting of various parts of the *Great Instauration*.

[54] *WFB* vol. XIV 373.

help for a work directed towards the future.[55] An important part of such a process of revision seems to be a reworking of his earlier notion of intellectual community, friendship,[56] teaching and communication of knowledge. The general notion which seems to lie behind all these efforts is that of the kind of public to whom the writings are directed. In one respect or another, most of Bacon's works from the last five years of his life are reworking of earlier ideas and theories with a double purpose: reaching to a larger public and opening the project of *Great Instauration* towards the future.

Levels of Readers: Secret and Public Knowledge

Secrecy is extremely important for Bacon, at every stage of his career, in theory and in practice. To start with the later, he both practiced and advocated the split between two kinds of writings: public writings and private manuscripts.[57] Each was designated for a different public; and the adaptation to the public is one of Bacon's main rules. As has been shown time and again, rhetoric is a very important component of Bacon's project, and: 'the proofs and persuasions of Rhetoric ought to differ according to auditors'.[58]

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[55] In some of the writings of the same period Bacon emphasize that he is writing for the future generations. See for example *Abecedarium novum naturae*, 1622, where the work is said to be 'for ages to come'.

[56] Bacon rewrites the essay "Of Friendship" with an emphasis on the importance of the friend as a literary executor and the one carrying on his friends projects. See also Jardine L. – Stewart A., *Hostage to Fortune* 519.

[57] In numerous writings Bacon comments on such a division. For example, in an early work, *Of the Interpretation of Nature*, a clear distinction is drawn between public and private writings: 'Now for my plan of publication – those parts of the work which have it for their object to find out and bring into correspondence such minds as are prepared and disposed for the argument, and to purge the floor of men's minds understandings, I wish to be published to the world and circulate from mouth to mouth; the rest I would have passed from hand to hand, with selection and judgment'. *WFB* vol. III 520. One of the manuscript copies of *Temporis Partus Masculus* bears an inscription with the phrase 'destined to be separate and not public'. See Leary J., *Francis Bacon and the Politics of Science* 200–201.

[58] *WFB* vol. III 411. See also *OFB* vol. IV 125. See Brian Vickers, *Francis Bacon and the Renaissance Prose*. Vickers thesis is that everything that Bacon wrote outside the field of Law was actually dedicated to his project for an advancement of learning, and was rewritten accordingly for a designated form of public. In what follows I am taking this thesis as an interpretative starting point.

There is a theory associated with such a practice. Studying nature is a complex process, described by Bacon in terms of a radical transformation of the human being. Getting into the 'inner chambers of nature' has all the connotations of a spiritual exercise and a spiritual purification which will change the state – or maybe even the essence of the mind.[59] For example, Bacon's doctrine of the idols ends, in *Novum Organum*, with a rewriting of a passage which is central in earlier writings, as well:

> So much concerning the several classes of Idols, and their equipage: all of which must be renounced and put away with a fixed and solemn determination, and the understanding thoroughly freed and cleansed; the entrance into the kingdom of man, founded on the science, being not much other than the entrance into the kingdom of heaven, whereunto none may enter, except as a little child.[60]

There are radical effects of such a transformation, some expressed in millenarian or apocalyptic terms,[61] some hinting to a restoration of an initial state the state of the first man in Paradise:[62] hence the related suggestion that not all the minds, not all the intellects are able to reach the end of the road. The pursuit of truth involves a process of selection.[63]

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[59] *OFB* vol. IV 50. See also the Plan of the Work of the Great Instauration. 'This doctrine then of the expurgation of the intellect to qualify it for dealing with truth, is comprised in three refutations: the refutation of the Philosophies, the refutation of the Demonstrations, and the refutation of the Natural Human Reason. The explanation of which things, and of the true relation between the nature of things and the nature of the mind, is as the strewing and decoration of the bridal chamber of the Mind and the Universe, the Divine Goodness assisting; out of which marriage let us hope (and be this the prayer of the bridal song) there may spring helps to man, and a line and race of inventions that may in some degree subdue and overcome the necessities and mysteries of humanity', *WFB* vol. IV 27.

[60] *WFB* vol. IV 68.

[61] Harrison P., "Original Sin and the Problem of Knowledge in Early Modern Europe", *Journal of the History of Ideas* (2002) 239–259.

[62] This is a subject widely discussed in connection with Bacon's theology. Milner, for example, points to a radical change in Bacon's theological views concerning the 'separation' between knowledge and faith from the early works to the late stage of his career where natural philosophy become something akin to theology. See Milner B., "Francis Bacon: The theological Foundations of Valerius Terminus", *Journal for the History of Ideas* 58 (1997) 245–264. However this may be, the possibility of using a particular approach towards knowledge to cure the mind and straighten the bended and distorted mirror, and therefore mending the effects of the Fall is variously expressed in early and late works as well. For example see *WFB* vol. III 222.

[63] There are numerous references to such a process of selection already in *The Advancement of Learning*, where the method of tradition (delivery of knowledge) is judged

Moreover, Bacon claims, there is something entirely new about the method or the content of his project, something that makes the transmission of it even harder, in comparison with other doctrines. Being new and difficult, it cannot be transmitted in the usual expositive way of an organized doctrine. Something else is necessary, like a disguise, for example: 'those whose Conceits are beyonde popular opinions, have a double labour; the one to make themselves conceived, and the other to prove and demonstrate.'[64]

As a result, no straightforward discourse is available for communicating the content, but a double level construction is necessary. At the bottom level, for the many, the purpose of discourse is to capture the imagination, to persuade and seduce (according to the capacity of the reader), using "parables and similitudes". Again, such a method of exposing knowledge is attributed to the ancients, and especially to one of Bacon's favourite characters, Democritus. However, only the use of such devices will draw attention to the new philosophy and will open the gate to the next stage, proper learning, while leading to the inner transformation of the mind.

In conclusion, there are at least two levels in the acquisition of knowledge, and, therefore, a similar division of discourse in transmitting the knowledge. The exoteric discourse lures the auditorium into the subject, inflaming its imagination, through rhetoric, similitude, parables; through creating wonder.[65] The second kind of knowledge transmission mediates a complex process of transformation in which the progressing disciple is purified and transformed during what seems to be a rather lengthy and tortuous process, sometimes described in medical terms.

Although a general method, Bacon's induction will not work in a clouded intellect, prisoner of its own idols. Therefore, from the beginning, the whole enterprise involving knowledge is structured on many levels: there is an outer circle of those never preoccupied by knowledge or learning, an intermediate level of those already on their way, and a

according to the audience, and the open delivery is fitted only for those capable 'of such sharpness as can pierce the veil' *WFB* vol. III 105.

[64] *OFB* vol. IV 125.

[65] The suggestion that wonder is a first step to knowledge is central to *Valerius Terminus* Also, in *The Advancement of Learning* wonder is said to be 'the seed of knowledge', *OFB* vol. IV 8. Wonder is a key issue in *New Atlantis* as well, where the gradual disclosure of secrets is destined to produce a permanent state of 'wonder' and hence to enhance the desire for further knowledge. *WFB* vol. III 218.

certain number of advanced students of nature able to understand and apply the method for the production of new knowledge. This splits the discourse from the very beginning and raises the problem of finding adequate methods of communication.

Knowledge, Wonder, and the Seeds of Knowledge

Bacon's first hint at how can this be solved is metaphorically explained in terms of the seeds of knowledge, one of Bacon's favourite metaphors. Aphorisms, for example, are said to be such seeds of knowledge, sowed in the human intellect, and able to encourage the mind to move forward on its way towards knowledge.[66] There are numerous advantages in writing aphorisms instead of an organized treatise: all connected with the intended effects in the audience. The aphorisms are an appeal to curiosity and wonder, a source of authority,[67] a sign that there is an implicit process of selection going on, that there is much more hidden under their surface,[68] and that the road of knowledge is open and ready to be explored by those willing to inquire further.[69] They are also ancient; bearing upon a respectable tradition and being the only remains of a much larger, but esoteric knowledge.[70] When used in natural history or

[66] 'aphorisms, representing knowledge broken, do invite men to inquire further' *WFB* vol. III 403. See also Milner "The theological foundations of *Valerius Terminus*" 262.

[67] In the classical tradition, as well as in the legal tradition so well known to Bacon, the aphorisms are maxims, axioms whose truth cannot be questioned; their model being Solomon's parable or the sayings of Hippocrates. Sessions W., *Francis Bacon Revisited* 34, Vickers B., *Francis Bacon and Renaissance Prose* 61–63.

[68] 'For first, it trieth the writer, whether he be superficial or solid; for Aphorisms, except they be ridiculous, cannot be made but of the pith and heart of sciences; for discourse of illustration is cut off; recitals of examples are cut off; discourse of connexion and order is cut off; descriptions of practices are cut off; so there remaineth nothing to fill the Aphorisms but some good quantity of observation; and therefore no man can suffice, nor in reason will attemt, to write Aphorisms, but that is sound and grounded'. *WFB* vol. III 405.

[69] Aphorisms 'did invite men [. . .] both to ponder tat which was invented, and to add and supply' *WFB* vol. III 498. See also Bacon's prefaces to the *Maxims of the law*: 'whereas I could have digested these rules into a certain method or order [. . .] I have avoided so to do because this delivering of knowledge in distinct and disjoined aphorism doth leave the wit of man more free to turn and toss, and to make use of that which is so delivered to more several purposes and applications' *WFB* vol. VII 312.

[70] As is for example described in *Fillum Labyrinthi*: 'Antiquity used to deliver the knowledge which the mind of man had gathered, in observations, aphorisms, or short and dispersed sentences, or small tractate of some parts that they had dilligently meditated and laboured' *WFB* vol. III 498.

natural philosophy, aphorisms are said to fulfil a number of functions: they stimulate curiosity, produce wonder and joy in front of the beauty and order of nature, represent open-ended questions[71] and are a sort of knowledge-in-the-making:

> But as young men when they knit and shape perfectly, do seldom grow to a further stature; so knowledge, while it is in aphorisms and observations, it is in growth; but when it once is comprehended in exact methods, it may perchance be further polished and illustrate, and accommodated for use and practice, but it increaseth no more in bulk and substance.[72]

However, because aphorisms are stimulating the imagination and hence are addressing the passions, they are a double-edge weapon:

> all knowledge and wonder (which is the seed of knowledge) is an impression of pleasure in it selfe; but when man fall to framing conclusion out of their knowledge, applying to their particular, and ministering to themselves, thereby features, or vast desires, there groweth that carefulnesse and trouble of the mind, which is spoken of: for then knowledge is no more Lumen Siccum, whereof Heraclitus the profound say *Lumen siccum optima anima*, but it becometh *Lumen maddidum*, or *maceratum*, being steeped and infused in the humors of the affections.[73]

Wonder seems to be a powerful ally to those involved in the advancement of learning because it is somehow connected with the initial process of preparing the mind. Meanwhile, creating wonder is just the beginning, the first step of a more complex process of transmitting knowledge according to the capacities of the readers.

The Theory of Communicating Knowledge in De Augmentis Scientiarum

In *De Augmentis Scientiarum* most of such ideas, images and suggestions concerning the transmission of knowledge are put together into what looks like a full blown theory on knowledge communication. It is called the ***wisdom of transmission*** or the ***passing of the lamp*** and introduces the readers to a couple of "methods" of teaching and learning. It starts from the same assumption that the very fact of learning is changing human mind; hence the necessity of a careful preparation.

[71] Vickers B., *Francis Bacon and Renaissance Prose* 83–84.
[72] *WFB* vol. III 392.
[73] *OFB* vol. IV 8.

Then, according to the level reached so far, there are three pairs of methods, one better than the other in terms of efficiency for the progress of knowledge.

The first such pair divides the transmission of knowledge according to the teaching method into *magistral* and *initiative*. The first delivers a discourse, the second is supposed to initiate the disciple into doing science himself. The first is for all, the second is for the few, for the 'true sons of science'. Its name, Bacon says, comes from the initiation practiced by the ancients during their mysteries.[74]

> I call the doctrine initiative (borrowing the term for the sacred ceremonies) which discloses and lays bare the very mysteries of the sciences. The magistral method teaches, the initiative intimates. The magistral method requires that what is told should be believed; the initiative that it should be examined. The one transmits knowledge to the crowd of learners; the other to the sons, as it were, of science. The end of one is the use of knowledges, as they now are; of the other the continuation and further progression of them.[75]

Of course, in a sense, the second method is novel and adapted by Bacon itself. However, we are told that it has old roots and that it is, in fact, a road 'abandoned and stopped up'. Two things are important about the *initiative*: it is described as a road to be travelled, in which the disciple and the master are supposed to advance together. It is also presented as an advance along the same path, with the same method which the knowledge was initially acquired. Bacon uses here another powerful and vivid image: knowledge like a growing plant, from the seed, in a prepared mind, if the proper method of transplantation is given. It is an image designed to convey the highly selective character of passing the lamp. It resembles, Bacon claims, with a second pair of ancient methods, the *exoteric* and the *acroamatic*, or *enigmatical*. They were mainly used in the process of selection associated with teaching: separating the chosen few able to penetrate the secrets of Nature. The trouble with this latter pair of methods is that it was repeatedly abused; although used with success among the ancients, was discredited by the moderns 'who have made it as a false and counterfeit light to put for-

[74] In the Advancement of Learning, the second method is called probation, and simply states that there is a method for the disciple to try by himself the content of what has been learned and maybe to make a step further on the road to wisdom. *OFB* vol. IV 123.

[75] *WFB* vol. IV 449.

ward their counterfeit merchandise'.[76] In its proper form, the third pair distinguishes between teaching a doctrine, or an organized discourse, called *method*, and presenting the disciples with *aphorisms*. A number of observations are necessary. First, it is obvious that Bacon uses here the term "method" in its ancient sense – *methodos*, system of teaching – as a reference not to the production of knowledge, but to teaching, learning, communicating knowledge.[77] It is therefore interesting that the last pair of methods is actually rewriting the distinction between aphorisms and theories. They are directed to two categories of readers and have different purposes. While both necessary for knowledge, they can easily be separated from the teacher's perspective. The aphorisms are enlisting curiosity, wonder, willingness to learn and hence help for the communal project of the *Great Instauration*; while more elaborate and secret methods are reserved for the selected few, or for further generations.

Gradual Disclosure of Secret in New Atlantis

It is time to go back now, to the fable of *New Atlantis* and read it against this theoretical background, as an application or illustration of the diversity of methods in transmitting knowledge. All previous devices are at work in it. The partial and gradual disclosure of the secrets of Bensalem is leaving the crew and the reader in a permanent state of wonder. At every stage, the revealing discourse is interrupted before reaching to a complete explanation. This might have a double purpose: on one hand, it is the "knowledge broken"; a literary device destined to inflate the curiosity and imagination. On the other hand is an illustration of the *initiative* method. The reader, as the sailors of *New Atlantis*, is lead into further inquiry and exploration. Moreover, as the story unfolds, we are witnessing the unfolding of a sort of quest. Each episode of disclosure is another trial where two things happens at once: the sailors are offering the "good" answer to a questions,[78]

[76] *WFB* vol. IV 450.

[77] This is also the Renaissance standard use of the term *methodos* in logic and rhetoric.

[78] Such is the answer to the first question-test: 'Are ye Christians?'. As a result of the good answer, the crew is permitted to land and the disclosure of secrets begins; *WFB* vol. III 131. Another test concerns the group of *questions* adressed by the sailors. Such is the question concerning the religion of Bensalemians. In response, the Governor of

showing themselves honest, humble, worthy of further advances on the road to knowledge *and* the number of those admitted into the inner circles of the Bensalemian society is reduced. In the last episode, the disclosure of the organization and procedures of Solomon's house, only one of the sailors is admitted into the presence of the Father of Solomon's House.

Such a quest has moral and religious undertones but it is also a process of self-knowledge and self evaluation: in the beginning, the sailors have 'time for thought', confined to the House of strangers; and in this context, they are told to *know themselves*, and *reform themselves*:

> My dear Friends; let us know ourselves, and how it standeth with us. We are Men vast of Land, as Ionas was, out of the Whales Belly, when we were as buried in the Deepe; and now we are on Land, we are but between Death and Life; for we are beyond both the Old World and the New; And whether ever we shall see Europe, God onely knoweth. It is a kind of miracle that brought us hither: And it must bee little lesse, that shall bring us hence. Therefore in regard of our Deliverance past, and our danger present, and to come, let us looke up to God, and every one reforme his own wayes.[79]

This request is formulated in very interesting terms: it does not refer only to a clever evaluation of the present situation in which the strangers found themselves, but it involves also something like the appeal to a deeper self-examination and reformation of conduct, an appeal to self-knowledge. Having escaped death, the strangers have also surpassed the boundaries of the known world. They are beyond the Old world not only in geographical, but also in spiritual terms. They are asked to examine their consciences and to reform their behavior (at least, if not their whole moral being). Moreover, they are asked to use the Bensalemians as their examples. Meanwhile, the passage reads, they are aware of being closely surveyed by the officials and of being put to some kind of test.

> For they have by Commandment (though in the forme of Courtesie) Cloistred us within these Walls for three Dayes; who knoweth, whether it be not, to take some tast of our manners and conditions? And if they finde them bad, to banish us straight-ways, if good, to give us further

the House of Strangers replies: 'You knit my heart to you by asking this question in the first place; for it showeth that you first seek the kingdom of heaven'; *WFB* 137.

[79] *New Atlantis*, 1629, 7; *WFB* vol. III 134.

> time. For these Men, that they have given us for Attendance, may withal have an eye upon us.

The request to behave is, however, formulated again in terms connected with self-knowledge, grace and salvation. Moreover, an entire series of theatrical devices are at hand in the story: as, for example, the fact that the existence, function, structure and story of Solomon's House is gradually revealed through the stories of three different characters wearing a sort of mask: the governor of the house of strangers (public identity), which is also priest "by vocation" (alluding to a private identity?), a Jew (which is not quite like a European Jew in terms of beliefs and behavior and who is surprisingly well informed about the island's secrets), and one of the mysterious fathers of the Brotherhood (one of the Interpreters of Nature, a sort of head-administrator of the institution, one of the lesser ranks of natural philosophers involved in the enterprise?).

In conclusion the quest and the road to knowledge involve self-knowledge, moral reformation, and a process of selection. The characters and, by reflection, the readers, have to prove themselves worthy of knowing the secrets. During this process which might be considered an illustration of the *initiative* method the sailors, and, presumably, some of the readers as well, are gradually changed, their minds or their imaginations having received numerous seeds of knowledge. Eventually, the outcome of such a procedure will be twofold: for some, wonder, the first step to knowledge. For others, the beginning of a new road, leading from the outer chamber of the "fable" to the inner chamber: the observations, experiments and facts presented in *Sylva Sylvarum*. Just a brief observation before passing further: it is interesting to notice Bacon's use of a direct language in *Sylva*: as if he is personally directing the reader to start the experiments himself. In a symbolical sense, at least, this is the practical realization of Solomon's House. And I would suggest that this is the actual meaning of Bacon's Brotherhood. What he had in mind was not a scientific research institute, nor a commonwealth of scientists, nor a secret society but, rather, a sort of regulative ideal with strong moral and religious connotations. And with a very respectable and recognizable tradition in the sixteenth century: the Stoic ideal wisdom, friendship of the wise and the moral transformation of the human being.

A Classical Source of Bacon's Brotherhood: Seneca's Epistles and Natural Questions

If we consider not the theatrical image of Solomon's House, but Bacon's presentation of New Atlantis in terms of communicating knowledge, then what we have here is an interesting understanding of philosophy as a way of life: a practical kind of philosophy, inducing profound transformations in the practitioners, both at the individual and at the political level. This is what Bacon is trying to persuade us: that there is a way of advancing the knowledge which has a strong impact on human mind, akin to an essential transformation; *and* that such a road to knowledge is to be travelled in common. He pictures himself as the one who is showing the way, leading by the hand the worthy disciple or "son of science", prescribing cures for the intellect, giving hope. Sometimes, in the discourse, he quotes directly from Stoical literature. Some other times he is paraphrasing ancient authors. Like, for example, in his letters of advice, where he is either quoting Seneca or heavily drawing upon similar Stoic literature.[80] The reference to a culture of the mind is developed in *De Augmentis Scientiarum*, with a thorough exposition of a sort of general Stoic outline of moral philosophy and a critique of Stoicism along the same lines with Lipsius, for example. What is more important, though, is Bacon's emphasis on the importance of knowledge, and especially natural knowledge in elaborating a proper moral philosophy and his claim that the best way to learn is by example.[81] There should be an accord and a continuation between natural philosophy and moral philosophy and such a culture of the mind should be but a continuation of the study of nature. Read in connection with Bacon's re-fashioning of his own image by drawing heavily on the model of Seneca, such references might be telling of the background against Bacon's last writings were supposed to be read by their first readers. But is the model itself recognizably Stoic? The straightforward answer to this question is "no". However, if we look less to the classical Stoicism and more to what has been recuperated at the end of sixteenth century both within the Neo-Stoic revival and through other mediums, some influential and recognizable themes of

[80] See, for example, Letter and discourse to Sir Henry Savill touching Helps for the Intellectual Powers, *WFB* vol. VII 97 ff. and Letter to the Earl of Rutland, *WFB* vol. IX 7.

[81] Letter to the Earl of Rutland, 'The first way to attain experience [...] is to make the mind itself an expert', *Works* vol. IX 7.

such background look much more familiar. Philosophy as a way of life, curing the mind, taming the passions while offering a road to wisdom open both to the active and contemplative person, a road to be travelled in common, by those in search of a tranquil life and willing to invest in the virtue of constancy; all these were common themes in the writings of Justus Lipsius,[82] Guillaume du Vair[83] and a number of other authors interested in the widespread literature on passions and various cures available for the fallen and imperfect mind. What such a literature does not contain – at least, not in an obvious way – is natural philosophy; the exploration of nature's secrets through experiments and the rules of a "scientific" community. However, if we start by investigating Seneca's views on the connection between moral philosophy and the study of nature *via* his theories of communicating knowledge and teaching, we can find something astonishingly similar with Bacon's vision of a structured and hierarchical community of natural philosophers.

Seneca's Model of an Ideal Community of the Wise

Few writings were more popular at the beginning of the seventeenth century than Seneca's *Epistles* and moral dialogues.[84] Countless editions and translations, either in English verse or in prose, complete or abridged, appeared in print between Erasmus editions of Seneca's works and the first complete English translation, that of Thomas Lodge, in 1614.[85] Among many other things, Seneca's moral works are offering an interesting model of the community of learners: the philosophers, lovers of wisdom, pursuing a life of philosophy in order to acquire, through a spectacular inner transformation,[86] Wisdom. It is a road to be travelled

[82] Lipsius J, *De Constantia*, translated into English by Stradling (London: 1586).

[83] A number of Du Vair works, including his *Moral Philosophy of the Stoicks* were translated into English around the beginning of seventeenth century and circulated widely in cultivated circles.

[84] On Senecan influence in England Protestant culture see Todd M., "Seneca and the Protestant Mind: the Influence of Stoicism on Puritan Ethics", *Archiv fur Reformationsgeschichte* 74 (1983) 182–99.

[85] A number of different statistics agree upon the increase in the number of editions: there seems to be at least 6 editions between 1475–1503, 7 between 1536–1580 and 10 from 1580 to 1604. In addition, the moral works were also published apart, in various forms, and in translations. See Todd, "Seneca and Protestant Mind" 184–185.

[86] Philosophy is often described as an inner transformation in its own right, as in Epistle 5,1. Therefore, the constant advice to reform ourselves Ep. 104,2 or to pursue

in common since all lovers of Wisdom are, by definition, in a relation of friendship.[87] Moreover, the very pursuit of philosophy is placing the disciple within a community of great minds, within his natural family.[88] The philosopher can choose his family of adoption.[89]

This ideal philosophical community is therefore hierarchically structured: the Wise are on top, in possession of moral virtue and knowledge alike, equal, tranquil and in many respects God-like; while the philosophers in pursuit of wisdom are still on the road, climbing the slopes of the mountain, trying to learn by example, moulding their intellects according to the powerful model of Wisdom taught by the books. The God-like character of the Wise, so central to early Stoics, has been transformed by Seneca into something more akin to a moral regulative ideal[90] and a promise of a sort of redemption through wisdom.[91] The acquiring of Wisdom is described in terms connected with theology: philosophy itself is said to be a path to heaven.[92]

Doing philosophy is a full program of study: a combination of spiritual exercises and the process of learning as much as possible (which means natural philosophy but also the philosophical doctrine of the Stoics, logics, dialectics; there is an entire programme of studies). Such a program of study is a prerequisite for a good and happy life and poses several problems concerning the social insertions of philosopher within the community. Since doing philosophy implies being constantly guided and ruled by reason, it also involves becoming a *natural* ruler;[93] hence the philosopher is a counsellor, teacher or king. However, in a very interesting shift of emphasis, Seneca addresses the question of

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the only form of life suitable for a tranquil and happy life. See for example Ep. 16, 1, Ep. 104, 22–23, *De Brevitate Vitae*, 15.

[87] The frienship of the wise and the subsequent friendship of the philosophers is one of Seneca's most common images. See for example Epistles, 6.7, 48.3, 52,8–9, *De tranquilitate animi*, 7.1–4.

[88] Ep. 104, *De Brev. Vitae*, 15.3.

[89] *De Brev. Vitae* 15.3.

[90] Hadot P., "La figure du sage dans l'Antiquite greco-latine", in Hadot P, *Exercises spirituels antique et "philosophie chretienne"* (Paris: 1987) 233–257, especially 245–246.

[91] According to Foucault, we can talk about a pre-Christian and philosophic model of salvation, similar in some respects (election, struggle, soldiering images of a battle etc.) with the religious one, but dissimilar in respect to the major cause since it is a salvation without an external saviour. See Foucault M., *Hermeneutica subiectului* (Bucuresti: 2001) 180–181.

[92] Epistle 48.11–12.

[93] Epistle 37.4.

the *natural* republic of the wise: sometimes that is said to be the entire world;[94] some other times, the community of philosophers.

There is a relevant moral dialogue *De otio*, where the discussion concerning a choice between *via activa* and *via contemplativa* is concluded in an intriguing way:

> But if that republic which we dream of can nowhere be found, leisure begins to be a necessity for all of us, because the one thing that might have been preferred to leisure nowhere is (nusquam est).[95]

There has been an interesting suggestion that this paragraph might have been a source behind More's "Utopia"[96] and the whole tradition of imaginary commonwealths of the seventeenth century. However this may be, it is important to stress that for Seneca, philosophy – a full program of study combining spiritual exercises, theoretical learning, reading and practical knowledge – is described *as if* it would take place within the ideal school of *all* philosophers of all times. The community is an ideal community, a big family of wisdom, with its own rules, customs and purposes. Such a model, however, goes far beyond the metaphorical level, into a full blown theory of teaching and learning. In Seneca's view, the admission into such a community of learners is to be regulated by the constant interaction with a teacher: an actual teacher or the ideal one, to be found in books.[97] The teacher is giving advice, leading by the hand, directing the studies, asking questions, supervising the moral behaviour and the life of the student. Or, at least, the student is asked to imagine such a role and to act accordingly.

Most of Seneca's writings are penned to show us such a model. They are addressed to prospective students of various level of proficiency. They represent the advice given by an absent teacher, in a sort of ideal school. Sometimes, Seneca express sadness over the fact that he cannot teach philosophy directly to his students saying that the real, great progress of the Stoics in Antiquity was due, in fact, to their life in common.[98] Since the life in common (*contubernium*) is no longer possible, the letters – in fact, the books – are meant to replace it, in an ideal

[94] *De Otio*, 4.1–2, *De tranquilitate animi*, 4.4.
[95] Seneca, *De otio*, Loeb Classical Library, *Moral Essays*, vol. II, translation Basore J.W. (Cambridge Massachusets: 1932) 200.
[96] Parrish J.M., "A new source for More's Utopia", *The Historical Journal* 40 (1997) 493–498.
[97] Philosophy in itself offers *counsel* to humanity. Epistle 48.8.
[98] Epistles 6.7, 104.22, *De Brev. Vit.* 15.

fashion. The correspondence is a school: with classes and exercises given, starting from the sentences and maxims, discussing percepts (*percepta*) and doctrines. Its pedagogical function, of transmitting knowledge, is, in fact, its only purpose. Now, it educates Seneca's students; in the future, it will educate its readers.

The model of the philosophical school is, therefore, projected upon an ideal community of writers and readers which will move the life in common in an ideal set. This is affecting the relation between the wise and the student – the wise is himself a *proficiens*, a philosopher, while the student can be himself an advanced student, hence a philosopher. Both master and student are struggling on the same road towards wisdom, they are part of the same group of friends (the true friendship between the sages being therefore translated at the level of the philosophers), of the same fraternity.

Where is natural philosophy coming in this picture? Again, a moral essay is offering us a precious hint. In discussing the advantages of active and contemplative life, in *De Otio*, Seneca is claiming that *via contemplativa* is, in fact, a life in the service of mankind. Why is it so? Mainly because it is a life directed towards our true purpose, which is living according to nature.[99] The true purpose of contemplative life is to act as witnesses to Nature, which means witnesses of Creation.[100] The study of nature is the true purpose of human reason and an activity in the service of mankind. Such a study of nature, though, involves not only what can be seen but mostly what has been kept secret: the big questions concerning the composition and duration of the universe, the universal law and the relation between man and divinity.[101] Here, Seneca seems to talk about a different kind of „science" or philosophy: theoretical, contemplative, divine. And, indeed, this is the kind of science developed in *Naturales Quaestiones*.

Natural Philosophy, Learning, and the Secrets of the Universe

Natural Questions is a strange work – in many respects as strange as Bacon's *Sylva Sylvarum*. It is even less structured in terms of grouping

[99] On the general discussion of *nature* and *natural* for the Stoics as opposed to *human*, see Hadot P., *Philosophy as a way of life* (Oxford: 1995), 207–208.

[100] *De Otio*, 4.2, 5.1, 5.3, 5.4, 5.7. *Naturales Questiones* I, Preface.

[101] *De Otio*, 5.5.

phenomena. It has seven books dealing mainly with meteorology, but also with cosmology and hinting to a matter theory. The first book explores various fiery phenomena and a whole bunch of optical illusions and has an extended digressions on mirrors, true and false reflections, philosophical meaning of mirrors and therapeutic use of mirrors for focusing one's attention and curing the passions of the soul. The second book deals with thunderbolts and other such phenomena, while the third and the fourth book seems to be about terrestrial waters. The fifth book is about winds, the sixth about earthquakes and the seventh about comets. Unlike his contemporaries, Seneca construct an entire theory of comets seen as celestial phenomena and celestial bodies moving through the universe according to the laws of nature. However, apart from this, the rest of Natural Questions did not receive much attention in the twentieth century. They were, of course, widely read in sixteenth and seventeenth century, although, arguably far less popular than Seneca's *Epistles.*[102] What is nevertheless extremely interesting is that the relation between Seneca's moral works and this work on natural philosophy was commented upon in the seventeenth century. *Natural Questions* were seen as supplementing the moral education of those in search of wisdom, communicating a further program of study and selecting the worthy readers. Such is, for example, Robert Boyle's reading of the work in *The Usefulness of Natural Philosophy.*[103]

The first book of *Natural questions* contains an extended explanation about the role of natural philosophy for the healing of one's soul and a sort of theory about communicating knowledge according to the levels of the students. For those who had completed their first part of education, for those who had managed to heal their mind and get rid of passions, there is a possibility of advancing into another kind of philosophy, divine and contemplative: the study of creation. Here Seneca claims that there are *two* kinds of philosophy: one teaches us what is to be done 'on earth', while the other lifts the soul to heaven.[104]

If the first branch is a sort of moral philosophy – understood in a practical, even technological sense, of large set of exercises, physical,

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[102] Hine H.M., "Seneca's Natural Questions-Changing Readerships", in L. Ayres (ed.), *The Passionate Intellect, Essays on the Transformation of Classical traditions* (London: 1995) 203–211.

[103] Robert Boyle, *Of the usefulnesse of Natural Philosophy. The First part. Of its Usefulnesse in reference to the Minde of Man* (Oxford: 1664) 2–3.

[104] *Naturales Quaestiones* I, 2.

mental and imaginative – the second is a sort of natural philosophy, or, rather, a natural theology, involving "penetrating into the mysteries of nature", learning the universal laws and order of the universe and understanding who is the Creator of the world and how is he acting inside his creation. Such study, claims Seneca, is the very purpose of human life. Now, what is really interesting is the way in which the relation between the two branches is explained. The first kind of philosophy is a sort of therapeutics, a medicine of the soul. Through it, we can cure our mind from the ilnesses of the soul. However, it is worthless without the second kind of philosophy, the knowledge of the natural world.[105] Without it, the whole practical philosophy was almost worthless 'you have escaped many ills, but you have not yet escaped yourself'.[106] Therefore, natural philosophy itself is not a separate branch of philosophy, but the next step of the same path in the road, accessible however, only to those already advanced. Through doing natural philosophy, the liberated intellect, free from passions, is able to discover the regimen of reason and, therefore, it becomes 'worthy to enter into association with god'.[107]

Such a passage of the mind from its bounded and ill state to virtue and freedom is described in terms of a travel into the depths of nature and into the immensity of the sky:

> The mind possesses the full and complete benefit of its human existence only when it spurns all evil, seeks the lofty and the deep, and enters the innermost secrets of nature. Then and the mind wanders among the very stars it delights in laughing at the mosaic floors of the rich and at the whole earth with all its gold. I do not mean only the fold which the earth has already produced and surrendered to be struck for money but also all the gold the earth has preserved hidden away for the avarice of future generations. The mind cannot despise colonnades, panelled ceilings gleaming with ivory […]. Until it goes around the entire universe and looking down upon the earth from above […] says to itself: "Is this that pinpoint which is divided by sword and fire among so many nations?"[108]

[105] For an interesting interpretation of this relation between natural and moral philosophy centered upon knowledge, see Foucault, *Hermeneutica Subiectului*, 269–70. By contrast, Hadot offers a reading centered upon the practical meaning of "spiritual exercises". Hadot, *Philosophy as a way of life.*

[106] *Natural Questions* I, Preface I.6., Loeb Classical edition, translation Corcoran.

[107] *Naturales Questiones*, I, Pref. I.6.

[108] 'Tunc consummatum habet plenumque bonum sortis humanae cum calcato omni malo petit altum et in interiorem naturae sinum venit. Tunc iuvat inter ipsa sidera vagantem divitum pavimenta ridere et totam cum auro suo terram, non illo tantum

The contemplation of the universe will then lead the mind back to moral philosophy; it can be therefore understood in terms of a spiritual exercise leading to a re-evaluation of theoretical knowledge and to a moral precept concerning the smallness of human life and the empire of man.[109] Seneca uses here another famous image:

> If someone should give human intellect to ants, will they not also divide a single floor into many provinces? Since you have aspired to truly great thoughts, whenever you see armies marching with flying banners, and a cavalry, as though engaged in something grand, scouting now at a distance, now massed on the flank, you will be glad to say:
>
> A black battle-line
> Moves on the plain.
>
> This army of yours is only a scurrying of ants toiling in a limited field. What difference is there between us and the ants, except the insignificant size of a tiny body.

It is relevant that such an image is taken by Bacon in a similar context, in *The Advancement of Learning*. Knowledge is leading directly to moral virtues, and the contemplation of the universe, the ascent of the mind has, as a result, both an increase in the understanding and a cure of the diseases of the soul. The passage reads:

> So certainly if a man meditate much upon the universall frame of nature, the earth with men upon it (the divinesse of soules except) will not seeme much other than an Ant-hill, whereas some Ants carrie corne, and some carrie their young, and some goe emptie, and all too fro and fro, a little heape of dust. It taketh away, or mitigateth feare of death, or adverse fortune, which is one of the great impediments of virtue.[110]

Bacon's argument in The Advancement of Learning actually follows Seneca's, since it continues with elaborating upon the way in which knowledge raises the mind, makes us able to recognize God's imprint in the universe and frees us from the slavery of passions. In Seneca's preface of NQ this is strongly expressed in terms of becoming like god:

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dico quod egessit et signandum monetae dedit, sed et illo quod in occulto servat posterorum avaritiae.' NQ I, 7 and 'Sic quis formicis det intellectum hominis, nonne et illae unam aream in multas provincias divident?' NQ I, pref. I., 10.

[109] For a general description of Stoic physics as a spiritual exercise see Hadot P., *Philosophy as a way of life*, 208–211.

[110] *OFB* vol. IV 49–50.

> Spaces in the heavens are immense; but your mind is admitted to the possession of them only if it retains very little of the body, only if it has worn away all the sordidness and unencumbered and light, flashes forth, satisfied with little. When the mind contacts those regions it is nurtured, grows and returns to its origin just as though freed from its chains.

However, what is described here it is only a temporary freedom of the mind, and a temporary acquisition of divinity through understanding. In reality, what the mind is capable of contemplating and understanding is just an extremely little fraction of the whole beauty and universe. And here, Seneca's program comes into play. There is a twofold project at work: the discovery of the secrets of nature ends in the 'good kind of contemplation', and therefore, is responsible for the ascent of the soul and for our moral progress. On other hand, the investigation of nature is, in itself, a very long, extremely complex and tedious business and cannot be done by one person. Help and collaboration are required, both between philosophers of the same age, as for philosophers of different generations. Seneca complains that he is just at the beginning, that he is old, and urges Lucillius, both for his own sake, and for the sake of the others, to join in the enterprise.

> I have decided to survey the universe, to uncover its causes and secrets, and to pass them to the knowledge of others.

In conclusion, for Seneca, the study of nature is helping us to free our mind and to overcome our fears, to endure life with a cheerful mind, while liberating our soul from the worst slavery, the slavery towards itself. The study of nature is also said to be useful, since it helps us towards our most important task, which is to live our life according to nature under the rule of the reason.

Seneca presents itself as merely a guide into this vast enterprise. He is showing the road to a faraway disciple, but a kindred spirit:

> Even though we are separated by the sea, I will try to supply this help to you: taking your hand in mine I will at once lead you away to a better life, and from here I will mingle my talk with yours so that you may not feel alone. We will be together in the part of us where we are best. We will give advice to each other, advice that will not depend on the facial expression of the listener.

Not all the world will be revealed, though and studying the secrets of nature is a gradual ascension to the truth.[111] However, there are good

[111] VII, 30 'How many other bodies besides these comets move in secret, never raising before the eyes of men! For god has not made all things for man. How much

reasons to believe that a community of learned men, sharing the results of their studies, would be able to move forwards than any of their predecessors.[112] What is needed for such a thing relates less to a good knowledge of theories, and much more to an active study of nature, sharing the results and moving forward with small steps and a keen eye on one's own moral development. Also, the actual result is less important than the road to come. The role of the philosopher seems to be connected with establishing such a path and then leading the way.

Can we go here beyond similarities, and establish a connection between Bacon and Seneca? Was Bacon drawing from Seneca, or working along a Senecan model? These are questions for further research. However, it is worth noting the fact that, at least towards the end of his life, Bacon was making several attempts to picture himself as following a similar "Senecan" model. Such a reference would have been *de rigueur* for the cultivated public targeted by Bacon's writings and it would have explained, also, their considerable success.

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a part of god's immense work is entrusted to us? The very one who handles the universe, who established it, who laid the foundations of all that is and placed it around himself, and who is the greater and better part of his work, and escaped our sight; he has to be perceived in thought. Moreover, many things related to the highest divinity or alloted a neighbouring power are obscure. Or perhaps – which may surprise you more – they both fill and elude our vision. Either their subtlety is greater than the human eye-sight is able to follow, or such a great majesty conceals itself in too holy a seclusion. It rules its kingdom – that is, itself – and grants no admission to any except the mind (soul).'

[112] VII, 30. 'Many things that are unknown to us the people of a coming age will know. Many discoveries are reserved for the ages still to come, when memory of us will have been effaced. Our universe is a sorry little affair unless it has in it something for every age to investigate.'

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THE WHALE UNDER THE MICROSCOPE: TECHNOLOGY AND OBJECTIVITY IN TWO RENAISSANCE UTOPIAS

Todd Andrew Borlik

In the year 1620 an English diplomat on an embassy to Germany witnessed a demonstration of an extraordinary optical device by the astronomer Johannes Kepler. He relayed the details of its design in a letter to a man with an avowed interest in such matters: Francis Bacon.

> He hath a little black tent set up, exactly close and dark, save at one hole, about an inch and a half in the diameter, to which he applies a long perspective trunk, with a convex lens fitted to the said hole, through which the visible radiations of all the objects without are intromitted, falling upon a paper, which is accommodated to receive them.[1]

Shortly after Bacon received this intelligence report, he had the chance to see the device in person when the natural philosopher-cum-entertainer Cornelius Drebbel arrived in London and dazzled the Jacobean court with displays of technological wizardry. In addition to chilling Westminster Hall with a primitive air-conditioner and plunging beneath the Thames for three hours in a submersible, Drebbel unveiled the apparatus that came to be known as the *camera obscura.* As Lord Chancellor, Bacon would have been in rapt attendance and very likely ventured inside the confines of the dark room himself. Four years later he would pen his utopian narrative, *New Atlantis*, in which a nation administered by a collective of scientist-sages known as Salomon's House astound a group of ship-wrecked Europeans with some of the exact same experiments performed by Drebbel.[2] Salomon's House has come to occupy a prestigious place in the annals of science. Often hailed as a prototype for the Royal Society, it has also been credited with anticipating the modern day research institute, N.A.S.A., the C.I.A. and the Smithsonian in one torrential brainstorm. But rather than simply unmask Bacon's

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[1] Wotton H., *Reliquiae Wottoniae, or, A Collection of Lives, Letters, Poems; with Characters of sundry personages* (London: 1654) 413–414.

[2] The connection between Drebbel and *The New Atlantis* was first proposed by Colie R.L., "Cornelius Drebbel and Saloman de Caus: Two Jacobean Models for Salomon's House", *Huntington Library Quarterly* 18 (1955) 245–260.

sources of inspiration, or marvel at his prescience, this paper examines how encounters with new innovations influenced his earth-shaking call for a scientific method that could produce truth-claims with pretensions to universal validity. The *camera obscura* offers a fascinating case-study of how early modern technology shapes Baconian epistemology.

Among the wonders of Bacon's utopia is a 'perspective house' where the scientists have assembled all the latest instruments that can distort or enhance the sense of sight. After flaunting their collection of prisms, telescopes, and microscopes, the guide boasts that they have acquired a secret means for producing 'multiplications of light, which we carry to great distances, and make so sharp as to discern small points and lines' (3, 161). This description of a device for the 'producing of light originally from divers bodies' (3, 162) virtually reads like a sales-pitch for the *camera obscura*. Though at no time does the text refer to it by name (neither does it explicitly mention the microscope or telescope for that matter), features of the 'perspective house' are clearly modeled on this contraption. By fixating on one sense while ignoring the other four, the *camera obscura* allows the natural philosopher to study the powers of human perception in isolation: an organizing principle in several of Bacon's works, such as the division of experiments in his *Sylva Sylvarum*. Moreover, Kepler and Drebbel's 'dark room' also exhibits several features found in the Benthalemite's blueprint of the ideal laboratory: 'remote alike from the sun and heaven's beams, and from the open air' (3, 156). The creation of an utterly separate arena for scientific inquiry, quarantined from the natural world, marks a sea-change in the methodology by which knowledge of that world would be pursued and ascertained.

In his provocative study, *Thing Knowledge*, David Baird argues that the standard modus operandi of 'examining' technological artifacts is inadequate and he urges critics to begin 'reading' them by resorting to the same deconstructive hermeneutics used to scrutinize literary texts.[3] The *camera obscura* makes a terrific candidate for such a reading because it is a representational, almost cinematic technology that bears a strange affinity to the mimetic practices of utopian fiction. Just as Stephen Greenblatt has famously described Holbein's 'Ambassadors' as the visual analogue to More's *Utopia*,[4] the *camera obscura* can throw

[3] Baird D., *Thing Knowledge* (Berkeley: 2004) xvii.
[4] Greenblatt S., *Renaissance Self-Fashioning* (Chicago: 1980) 17–24.

light, as it were, on *The New Atlantis*. The difference between the painting and the technology highlight Bacon's divergence from his literary predecessor; while painting is static, the *camera obscura* projects the image of a world *turned upside down and in motion.* In a corresponding fashion the *New Atlantis* depicts a dynamic society where power is primarily invested not in the monarch but in a meritocracy of scientist-sages. Appropriately the Benthalemites, unlike the citizens of More's ideal commonwealth who already bask on the summit of their history, subscribe to an interminable narrative of intellectual and material progress. The people of *New Atlantis* are ever expanding their knowledge of and dominion over the natural world to become, in a paradoxical phrase Bacon uses elsewhere, 'more perfect' (4, 14). Furthermore, whereas Holbein's portrait requires viewers to reposition themselves in order to un-distort the skull in the foreground, the operation of the *camera obscura* requires an absolute withdrawal from the natural world, a retreat into an entirely artificial, humanly constructed space. Temporarily interred within its walls, the natural philosopher can engage in a kind of environmental voyeurism, perceiving the outside world in serene detachment while remaining unseen by the objects under surveillance. The experience may even have spurred the obsession with invisibility that surfaces again and again in *The New Atlantis*. It is mentioned so frequently that one can almost imagine the Benthalemites writing a scientific treatise with the title of a Monty Python sketch: 'How Not To Be Seen.' The European sailors are repeatedly awed by their hosts' ability to survey them undetected: 'For that it seemed to us a condition and propriety of divine powers and beings, to be hidden and unseen to others, and yet to have others open and *as in a light to them*' (3, 140; italic mine). The invisibility motif also features in the description of the Feast of the Family, the travels of the Merchants of Light, and the anonymity of the island itself – allowing it to explore the rest of the world yet remain undiscovered by foreign powers. The recurrence of this fantasy in the text is, I believe, no accident. It symbolizes a more grandiose fantasy of which Bacon is often upheld as the leading apostle: namely, the self-effacement of the scientist while examining the natural world. The *camera obscura* illustrates how technology, in particular the technology of surveillance, contributes to the formation of a discourse of objectivity in Bacon's writings.

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In tandem with the painting of Hamlet as the poster-child of modern subjectivity, recent criticism has sought to cast Francis Bacon as the spokesperson of scientific objectivity. The nomination, advanced by respected historians of science such as Lorraine Daston and Julie Robin Solomon, certainly makes a great deal of sense.[5] In the *Novum Organum* Bacon famously outlines a methodology that strives to eliminate or neutralize the theoretical, cultural, or personal bias of the scientist, and enable him through induction and experimentation to extract brute 'facts' from the flux of experience. The experiment, rather than the observer's intellect, now serves as the ultimate court of appeal: 'the office of the sense shall be only to judge of the experiment, and that the experiment itself shall judge of the thing' (4, 26). This vision of an infallible, universal science seized Bacon as early as *The Advancement of Learning* (1605) in which he cites a passage from Lucretius endorsing the natural philosopher's olympian detachment:

> It is a view of delight (saith he) to stand or walk upon the shore side, and to see a ship tossed with tempest upon the sea; or to be in a fortified tower, and to see two battles join upon a plain. But it is a pleasure incomparable, for the mind of man to be settled, landed, and fortified in the certainty of truth; and from thence to descry and behold the errors, perturbations, labours, and wanderings up and down of other men (3, 317–8).

The excerpt may have supplied him with the premise of another text he would compose two decades later, *The New Atlantis*, in which the intrepid Benthalemites rescue the feckless Europeans blown off course by a storm. This work of speculative fiction essentially recounts a quest for discursive stability in natural philosophy. In other words it imagines the discovery of an objective viewpoint from which superstitions and fallacies could be denounced (not without a hint of *schaden-freude* as the passage from Lucretius suggests) and truth-claims posited and disseminated.

The fable aptly culminates in an encomium to Salomon's House, whose members engage in collaborative research. Together they constitute a kind of intellectual commonwealth in which the interests of specific individuals and social classes are sublimated in the pursuit of

[5] Daston L., "Baconian Facts, Academic Civility, and the Pre-History of Objectivity", in A. Megill (ed.), *Rethinking Objectivity* (Durham: 1994) 37–63. Solomon J.R., *Objectivity in the Making: Francis Bacon and the Politics of Inquiry* (Baltimore: 1998).

one over-arching agenda: 'the enlarging of the bounds of Human Empire' (3, 156). The anonymous hermits the college employs in its investigations nicely embody the philosophers' aloofness from mundane concerns that might tempt them to spin-doctor the results. With its division of academic labor involving fact-checking, the replication of experiments by third parties, the publication of results, and a rigorous peer review process, Salomon's House has been recognized at least since the time of Thomas Spratt as a pioneering formation of the modern scientific community. Less well documented is the active role of *objects in objectivity*, the collusion of technologies like the *camera obscura* in carving out a space for disinterested observation. Although Bacon's program is heavily influenced by the political and socio-economic tensions of his milieu, more attention needs to be paid to the function of such artifacts in the evolutionary epistemology of human beings. Bacon himself nods to their impact when he refers to a trinity of modern inventions – the magnet, the printing press, and gunpowder – and proclaims: 'no empire, no sect, no star seems to have exerted greater power and influence in human affairs than these mechanical discoveries' (4, 114).

More than any other text from the period *The New Atlantis* showcases the correlation between the technological take-off of the West and the theory of a universal science. Significantly, as the head of Salomon's House lists all of their engineering marvels, the text shifts abruptly from first person singular to the first person plural. Thirty of the final thirty-seven paragraphs begin with 'We', as do a similar percentage of sentences within each paragraph. The grammar reinforces Bacon's notion of science as a collective enterprise and fits with his belief that such inventions will serve to improve the lot of all mankind. The switch reflects the fact that Baconian objectivity is predicated upon access to and mastery of technology. Conspicuously absent from the account is any mention of the arduous labor involved in the construction, operation, and maintenance of these devices. As in the creation story from Genesis, the inventions of the College of the Six Days' Works – such as observatories, wind machines, air filters, furnaces, telephones, clockwork automata – appear to have been forged by mystical fiat rather than any physical exertion. The bland verbs that somewhat monotonously dot the catalogue of technology – 'have', 'use', 'represent' – serve an important rhetorical function by reducing the scientists to mere ciphers. Bacon's prose thus invests the gadgets with a remarkable agency while the researchers themselves appear astonishingly inert, heightening the impression of human impartiality.

While scholars have justly traced the germination of objectivity back to Bacon's work some important caveats must be kept in mind to check anachronistic assertions. Rather than speak of 'facts', a buzzword singled out by Daston, Bacon by far prefers the term 'axioms' to signify a rudimentary and indubitable truth-claim about nature. And at no point does Bacon deploy the word 'objectivity' in the modern sense, being more likely to refer to the 'certainty' of the 'human understanding.' There is a simple explanation for this: 'certainty' conveyed both the idea of mental constancy and a fixedness in nature while the first usage of 'objectivity' to refer to the capacity to pronounce a disinterested judgment only dates from 1803. Nor could he reach for the shortened form 'objective.' This adjective did not yet even allude to the thing's existence independent of its beholder – a definition introduced into the language by Coleridge via Kant. In fact in the seventeenth century 'objective' carried nearly the opposite meaning: the registering of objects within the consciousness of the subject, their mental in contrast to their real existence.

This earlier sense – which effectively endowed material things with a greater ability to penetrate the mind – gave rise to yet another definition of 'objective' in the early modern era that spotlights the role of technology in the advent of scientific disinterestedness. In 1671 a paper appeared in the transactions of the Royal Society distinguishing between two reflective surfaces on a microscope by declaring that 'the eye is always more distant from the convex *objective* glass than its point of concourse.' According to the OED, 'objective' here designates 'the lens or combination of lenses in a refracting telescope or microscope that is nearest the object to be viewed.' Note that the use of the term to refer to a piece of an optical instrument precedes by over a century its connotations with the absolute neutrality of the observer. Though microscope design was still fairly primitive in England prior to the publication of Hooke's treatise on the subject in 1665, Bacon knew that reflective mirrors could be used for the purposes of magnification. The sages of Salomon's House possess certain 'glasses', far more powerful than spectacles, that allow them 'to see small and minute bodies perfectly and distinctly' (3, 162). Just as the microscope contributed to the new meaning of objective, Bacon seizes on the technology of optics in the *Novum Organum* to craft a theory of impartiality by comparing the human understanding to a mirror (4, 54). When imperfectly fashioned it distorts and colors the impressions it receives. By following Bacon's prescription for the 'expiations and purgings of the mind', however, the

natural philosopher's understanding can be 'cleansed' so as to reflect reality like an unblemished glass. The metaphor reveals how Bacon internalizes the contrivances of 'art', in this case medicine and microscopes, to transform the conventional understanding of 'nature.'

One of the most important planks in Bacon's platform is to collapse the art/nature binary to sanction the use of scientific instruments to wrest raw data from the biophysical world. In a memorable phrase from *The Advancement of Learning* he proclaims 'Vulcan is a second nature' (3, 351), implying that a scientific experiment merely serves to accelerate an organic process without fundamentally altering the results. Bacon goes on to posit that technology is not only a useful supplement but also an essential corrective for the vagaries of human perception. As he declares at the beginning of the *Novum Organum*: 'Neither the naked hand nor the understanding left to itself can effect much. *It is by instruments and helps that the work is done*, which are as much wanted for the understanding as the hand' (4, 47). By championing the use of instruments to aid the intellect, Bacon's writings consecrate technology as a means to duck the four key obstacles to objective thought he identifies in the *Novum Organum*. By extending the relatively feeble reach of our sensory apparatus, it mitigates the effects of the Idol of the Tribe. In its seemingly unbiased reporting of events it overcomes the personal and cultural idiosyncrasies he labels the Idols of the Cave. Through its ability to transmit information without language it evades the Idols of the Marketplace. And finally, in its capacity to generate axioms unknown to the ancients it liberates natural philosophers from blind faith in outdated systems – the Idols of the Theatre.

In his aforementioned book on the 'philosophy' of scientific instruments David Baird argues that technologies are themselves epistemologically loaded – that is, they are capable not only of processing but actually bearing knowledge. He points to the numerous occasions in which scientists and mechanics sent out the devices themselves, instead of written descriptions, as witnesses of their own innovation.[6] Bacon makes a similar observation in *The Advancement of Learning*. He recalls that Aristotle once mocked his opponents by comparing them to cobblers who instead of teaching how to make a shoe would 'only exhibit in a readiness a number of shoes of all fashions and sizes.' Bacon tellingly sides with the Sophists: 'But yet a man might reply, that

[6] Baird D., *Thing Knowledge* 3–8.

if a shoemaker should have no shoes in his shop, but only work as he is bespoken, he should be weakly customed' (3, 390). The analogy of the cobbler's shop serves to explain how scientific instruments not only generate, but encode and preserve information. Bacon is even more explicit in *The Great Instauration*, noting that in a lecture on mathematics 'it is easy to follow the demonstration when you have a machine beside you, whereas without that help all appears involved and more subtle than it really is' (4, 31). This same logic inspires Bacon to dream up the first gallery in *The New Atlantis* which the members of Salomon's House stock with 'all manner of the more rare and excellent inventions' (3, 165). The gallery – part religious shrine, part Museum of Science and Industry – is intended to commemorate past innovations and more importantly spur new ones. When placed before the proper audience these tools and machines essentially do what authors do: they tell stories. This leads, I would suggest, to a slight modification of Foucault's theory of the vanishing of the author-function in modern scientific writing: it does not disappear completely but rather is transferred to the instruments. Scientists no longer appeal to the authority of all-knowing Aristotle or Galen to support their hypothesis but to the infallible and impartial microscope. The upshot is the displacement of objectivity onto technology. This displacement is perhaps most apparent in the next generations of scientists such as Boyle, although in the following passage the influence of Bacon is abundantly evident:

> The pressure of the water in our recited experiment [on the diver's bell] having manifest effects upon inanimate bodies, which are not capable of prepossessions, or giving us partial informations, will have much more weight with unprejudiced persons, than the suspicious, and sometimes disagreeing accounts of ignorant divers, whom prejudicate opinions may much sway, and whose very sensations, as those of other vulgar men, may be influenced by predispositions, and so many other circumstances that they may easily give occasion to mistake.

In a similar fashion Boyle once coolly responded to a critic who had challenged his findings: '[I] question not [his] Ratiocination, but only the staunchness of his pump.'[7] Boyle's concern with the 'prejudicate opinions' of others, and his faith in the ability of technology to neutralize them, both derive from Francis Bacon. But not everyone was

[7] Robert Boyle, "Hydrostatical Discourse", 614–15; Boyle to Moray, July 1662, in Christian Huygens, *Oeuvres* (Hague: 1888–1950) 4, 220; rptd. in Shapin S. – Schaffer S., *Leviathan and the Air Pump* (Princeton: 1985) 218, 77.

instantly persuaded of the epistemological validity of using instruments as tools for manufacturing truth-claims. Among the next generation of natural philosophers Bacon's faith in technology sparked not only adulation, but also debate and even parody.

* * *

Francis Bacon's quest to inaugurate a universal science has never lacked detractors. In that early modern anthology of celebrity gossip, Aubrey's *Brief Lives*, William Harvey snidely remarks that his contemporary and sometime patient 'writes philosophy like a Lord Chancellor.'[8] Almost four centuries later a chorus of critics have echoed Harvey's snub, exposing the social and historical contingencies that mold Baconian epistemology. The gadflies of post-structuralist theory have swarmed on the claim to scientific objectivity, denouncing it as a hubristic flight of fancy that inevitably constructs and enshrines an aristocratic male outlook on the natural world. Julie Robin Solomon has shown that Bacon conflates the scientist's perspective on nature with the monarch's allegedly disinterested authority over his domains; Steven Shapin posits that the 'Idols of the Cave' was meant to disqualify merchants obliged to consider their material self-interests; while Carolyn Merchant has accused Bacon of appropriating the interrogative tactics of the early modern legal system to underwrite the impartial (and sadistic) inquisition of the natural world.[9] The fact that a theory of universal science receives a key articulation in a utopian narrative now seems exceptionally apt, as criticism has sought to unmask objectivity as a voyage to an epistemological Shangri-la. Yet long before the current wave of skepticism broke, the bias in Bacon's mechanistic science was spelled out in another seventeenth-century English utopia, *The Blazing World* by Margaret Cavendish, the Duchess of Newcastle. Remarkably, her critique does not target any of the aspects mentioned above, but exposes the dubious use of technology as a means to generate and verify truth-claims.

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[8] John Aubrey, *Brief Lives* (London: 1950) 130.

[9] Solomon J.R., *Objectivity in the Making: Francis Bacon and the Politics of Inquiry*; Shapin S., *A Social History of Truth: Civility and Science in Seventeenth Century England* (Chicago: 1994) 224–5; Merchant C., *Death of Nature: Women, Ecology and the Scientific Revolution* (New York: 1980).

The Blazing World recounts the journey of a well-born English woman who, as the lone survivor of an ill-fated voyage, drifts ashore in another world poised on top of the North Pole. Here she encounters a technologically advanced race of mutant creatures. Overwhelmed by her natural beauty, they promptly arrange a marriage with their ruler and crown her Empress. From her throne she surveys the state of their learning. In the following extract she consults her astronomers, men with the heads of bears, eager to hear of the marvelous discoveries they have glimpsed through their powerful telescopes. The results prove disappointing.

> But these telescopes caused more differences and divisions amongst than ever they had before; for some said, they perceived that the sun stood still, and the earth did move about it, others were of opinion, that they both did move; and others said again that the earth stood still, and the sun did move; some counted more stars than others; some discovered new stars never seen before; some fell into a great dispute with others concerning the bigness of the stars; some said the moon was another world like their terrestrial globe, and the spots therein were hills and valleys, but others would have the spots to be the terrestrial parts and the smooth and glossy parts, the sea.[10]

As in Montaigne's *Apology for Raymond Sebond* the sheer proliferation of widely divergent yet plausible theories renders the search for a single definitive truth absurd. Rather than contributing to the consensual validation of scientific 'axioms,' technology breeds controversy and dissension. Frustrated by their disagreements, the Empress orders the astronomers to smash their telescopes.

> The bear-men replied, that it was not the fault of their glasses, which caused such differences in their opinions, but the sensitive motions in their optic organs did not move alike, nor were their rational judgments always regular: to which the Empress answered, that if their glasses were true informers, they would rectify their irregular sense and reason; but, said she, nature has made your sense and reason more regular than art has your glasses, for they are mere deluders and will never lead you to the knowledge of truth. (141–2)

Repeatedly the text uncovers that the much-vaunted scientific instruments cannot overcome either human error or self-interest. The satire

[10] Margaret Cavendish, *The Description of a New World Called The Blazing World And Other Writings* (New York: 1992) 140–1. Subsequent citations from this edition will be noted in the text.

reaches a climax when the Worm-men arrive and the Empress demands they make a patently absurd attempt to examine a whale under a microscope. The scene serves as a humbling reminder of the limitations of technology as a springboard to a domineering, omniscient perspective over the natural world.

Cavendish, the first woman ever permitted to attend a meeting of the Royal Society, here inveighs against a scientific enterprise directed exclusively by men. Oddly enough, Pepys noted her visit in his diary and reported 'Margaret was full of admiration, all admiration.'[11] Even after observing several experiments 'she cried out still she was "full of admiration."' Yet *The Blazing World* tells a rather different tale. A woman enters the halls of science and immediately debunks the technologies invented and operated by the men as unreliable, if not outright fraudulent. And in a clever parody, the scientists – whose reason and research seems bent on catapulting mankind above the rest of brute creation – have been spliced with the heads of various animals: bears, worms, dogs, and birds. Utopian fiction offers Cavendish the chance to found her own private textual empire from which to wage campaigns against men like Bacon, Boyle, and Pepys and grant herself the intellectual authority her culture denied her.

The past few decades have witnessed a long overdue surge of interest in Cavendish's scientific writings: Carolyn Merchant, Sylvia Bowerbank, and Sarah Hutton have all celebrated her works as an eco-friendly alternative to the ruthless mechanism outlined by Bacon.[12] As opposed to the *Novum Organum*'s vision of an inanimate environment freely manipulated by mankind, her *Observations Upon Experimental Philosophy* sets forth a system of organic materialism that sees Nature as a living, self-moving, self-aware entity. Whereas Bacon's asserts that 'Vulcan is a second nature', Cavendish declares that artificial experiments are only 'partly natural', reproducing an isolated phenomenon 'like an emulating ape' without understanding it. Finally, as if in a deliberate bid to rival him, she appends *The Blazing World* to her scientific treatise just as he had attached *The New Atlantis* to the *Sylva Sylvarum*. In light of

[11] Samuel Pepys, *Diary* (Berkely: 1970–83) vol. 8, 242–3 (30 May/9 June 1667).

[12] Merchant C., *Death of Nature*; Bowerbank S., "The Spider's Delight: Margaret Cavendish and the 'Female' Imagination", in Farrell K. – Hageman E. – Kinney A. (eds.), *Women in the Renaissance* (Amherst: 1990) 187–203; Hutton S., "Science and Satire: The Lucianic Voice of Margaret Cavendish's *Description of a New World Called the Blazing World*", in Cottegnies L. – Weitz N. (eds.), *Authorial Conquests* (London: 2003) 161–78.

the parallels between the utopias it seems a plausible conjecture that Bacon's legacy is the main quarry her satire pursues. But Cavendish's relationship to Bacon is in fact far more complex than either this essay or prior studies on the topic have yet implied. If Cavendish saw herself as the belated nemesis of Bacon, why does she refrain from mentioning him directly in either *The Blazing World* or the *Observations*? After all she does single out the theories of Gassendi, Descartes, Hobbes, and Henry More for rebuttal on several occasions. Can her silence simply be chalked up to *de mortuis nil nisi bonum*? One possible explanation for the clemency shown to Bacon is that the two thinkers have more in common than a cursory glance at their works or current critical reputations would indicate.

Cavendish has long suffered under the aspersions that her natural philosophy was erratic and inconsistent;[13] in her dogged pursuit of truth she espouses a number of seemingly conflicting opinions, including theories that rely on technology or embrace mechanistic principles, as in her chapters 'Of Natural Matter and Motion' (199) and 'Of Natural Sense and Reason', where she accepts Glanvill's proposition that the body and the mind are 'moved by the inward springs and wheels of the corporeal machine' (215). But if Cavendish can be taxed for contradictions, neither is Bacon's philosophy exempt from the same charge. For instance some of his early works (not published until 1653) express enthusiasm for Democritus' materialist doctrines on the vacuum and the immutable atom. Though he eventually rejected these teachings in the *Novum Organum*, Cavendish found them congenial and may have borrowed from Bacon's early commentaries to formulate her materialist ontology.[14] Rather than condemn their writings as a hopeless muddle, the discrepancies are a sign of their intellectual honesty. Given that both Bacon and Cavendish were continually refining, rescinding, and/or updating their theories over several decades, it is not surprising their opinions would periodically intersect. Most recent studies on the Duchess, while acknowledging her inconsistencies, have focused almost exclusively on her skepticism toward the male scientific establishment and read *The Blazing World* as a compensatory fantasy, a retreat into

[13] See for instance Perry H.T.E., *The First Duchess of Newcastle and Her Husband as Figures in Literary History* (Boston: 1918) 197; Woolf V., *A Room of One's Own* (New York: 1929) 65.

[14] See E. O'Neil's introduction to the *Observations Upon Experimental Philosophy* (Cambridge: 2001) xiv.

radical subjectivity.[15] But there is another strain in Cavendish's philosophy that embraces the Baconian vision of a universal, impartial science engaged in the discovery of 'natural truths.' A more nuanced comparison of their writings reveals that Cavendish at times entertains the possibility of objective knowledge, while Bacon's later works display a marked ambivalence toward technology that anticipates aspects of Cavendish's critique.

Cavendish's quarrel with Baconian science rests more with its means than with its ends. In other words, while she rejects the use of technology that effectively grants men a monopoly on the production of scientific knowledge, she does not dismiss objectivity outright as a philosopher's pipedream. On the contrary, the preface to her utopia avers 'there is but one truth in nature' (123), and much of the book that follows consists of an attempt to ascertain it. In addition to attacking Descartes, Boyle, and Hobbes, Cavendish also hurls some of her most venomous invective at the teachings of skepticism, in both its classical and modern dispensations. To the extent they deny the possibility of genuine knowledge, Cavendish deems 'their doctrine is not only unprofitable, but dangerous' (214). Cavendish proceeds to call on skeptics and overly confident dogmatists to set aside their differences and adopt a less biased approach that strives for consensus rather controversy, and 'make *an harmonious consort and union in the truth of nature*' (214).

As we have seen, the notion of objectivity, to the extent it existed in the early modern period, was closely knitted to certainty and impartiality. In her utopia Cavendish assumes this discursive pose through the persona of the inquisitive Empress. As a stranger to the realm she ostensibly has no pre-existing political agenda; nor do personal or fiscal interests warp her judgment. Wielding a comprehensive knowledge of current scientific theories and the supreme authority to accept, question, denounce, or modify them, the Empress can be seen as an incarnation of the objective mind. Of course this is not to say that Cavendish herself succeeds in attaining absolute neutrality: in selecting an Empress as her mouthpiece she even more blatantly than Bacon conflates objectivity with a royalist point of view. Coming from the pen of a Duchess, the theory of a universal order in nature may be justly suspected of shielding

[15] Bowerbank S., "The Spider's Delight"; Sarasohn L., "A Science Turned Upside Down", *Huntington Library Quarterly* 47 (1984) 289–307; Whitaker K., *Mad Madge: The Extraordinary Life of the Duchess of Newcastle* (New York: 2002) 307.

a desire to preserve the fragile peace of the Restoration – hence her denunciation of skepticism as 'dangerous'. But Cavendish also seems to sense that a truly unbiased methodology could present a loophole allowing women under the tent of the scientific community. When the Empress decides to hire a scribe to record her decrees, she rejects Plato, Pythagoras, Gassendi, Descartes, and Hobbes on the grounds that they are 'wedded to their own opinions' and too 'self-conceited' to respect a woman. Instead she selects the Duchess of Newcastle since 'although she is not one of the most learned, eloquent, witty and ingenious, yet she is a plain and rational writer' (181). In a brilliant rhetorical parry, Cavendish turns her lack of a university education into an asset. Her alleged simplicity endows her with superior epistemological credentials: a mind guided by reason rather than presupposition, which therefore pays no homage to the Idols of the Theatre. Shortly afterwards the disembodied spirits of the two women depart the Blazing World to float above the earth and 'in a moment viewed all the parts of it, and all the actions of the creatures therein' (190). The text here imagines an omniscient and disinterested perspective on the phenomenal world, one attained by the powers of reason and imagination rather than the promise of technology.

In a curious passage from the *Observations* Cavendish refers to technology as a 'hermaphroditical' art. As a woman who literally barged into the male-dominated scientific community, her word-choice would practically scream of authorial self-consciousness. By calling the new devices 'hermaphroditical' she projects onto them her own daring program to infuse natural philosophy (and its patriarchal authority over nature) with her feminist perspective. But rather than substitute the outpourings of her 'female imagination' for the rational methodology of her male contemporaries,[16] Cavendish more often than not promotes her work as offering a vital supplement. Just as she attaches *The Blazing World* to the *Observations*, Cavendish's lengthy prefaces and epilogues fashion a self-image that is both highly creative and eminently rational. Although she deflects criticism for her bold scheme onto technology, she in effect formulates a hermaphroditic epistemology with the aim of inaugurating a science that is truly universal and objective.

Cavendish's hostility toward the mechanical arts also relaxes on several occasions. Despite the Empress ordering the Worm-men to

[16] Bowerbank S., "The Spider's Delight".

smash their telescopes, Cavendish was no Luddite. In fact some of her early writings exhibit an avid interest in scientific instruments and the potential discoveries they could unlock. In 1657 she composed a detailed letter to Constantijn Huygens that evinces both fascination with the microscope and some expertise in operating one.[17] Even the sailors of the Blazing World have equipped their ships with motors which the narrator deems an 'extraordinary art, much to be taken notice of by experimental philosophers' (129). And it is worth recalling that the Empress's order to destroy the 'deluding glasses' is not actually obeyed. To be sure, by the time she penned her later works her enthusiasm for such devices had soured. Though criticism has recognized her disillusion with technology, it has not fully unraveled the motives behind it. Hilda Smith speculates that Cavendish turned against the new instruments because of their failure to produce practical results.[18] While Smith's point is well-taken, I would argue that the Duchess's aversion primarily springs from a sense that these tools problematize the search for objective knowledge. While Bacon boasts of the glasses by which the members of Salomon's House manipulate light at their whim, Cavendish's chapter on micrography complains that these devices produce 'so many alterations made by several lights, their shadows, refractions, reflexions, as also several lines, points, mediums, interposing and intermixing parts, forms and positions, as *the truth of an object* will hardly be known' (50; italics mine). This would seem to point to a fundamental difference between the two thinkers: whereas Bacon attempts to naturalize technology, Cavendish relies on technology to define the natural, drawing a distinction between 'artificial delusions' and 'natural truths' (142).

But again to portray the two thinkers as bitterly and hopelessly divided on this issue would be reductive. First off, Cavendish is most likely not reacting to Bacon here but to Hooke's *Micrographia*, which appeared in 1665, the year before she wrote *Observations* and *The Blazing World*. Secondly, close scrutiny of Bacon's writings reveals that he shares Cavendish's concern to distinguish between 'artificial delusions' and 'natural truths.' Though Cavendish's suspicion is more pronounced, it is as if both thinkers gradually realized that new technologies raise more

[17] British Library, Add. Ms. 28558. f.65.

[18] Smith H., "Margaret Cavendish and the Microscope as Play", in J. Zinsser (ed.), *Men, Women, and the Birthing of Modern Science* (DeKalb: 2005) 48–70.

interpretive difficulties than they resolve. Bacon too was keenly aware that these devices could be exploited to mislead the senses, thus admitting the possibility that the data they generated in experiments might also be chimerical. In addition to the *camera obscura* he had personally witnessed Drebbel perform a series of optical illusions with specially designed lanterns to make his silhouette assume the shape of a lion, a bear, a pig and even a tree with fluttering leaves.[19] Recognizing that their use in parlor tricks might sabotage his program, he actually equates the frisson of delight people feel at such *trompe l'oeil* with sexual arousal: 'With arts voluptuary I couple practices joculary; for the deceiving of the sense is one of the pleasures of the senses' (3, 379). Thus his litany of technological marvels in the *New Atlantis* concludes with a firm commandment outlawing any practices that smack of magic:

> But we do hate all impostures and lies; insomuch as we have severely forbidden it to all our fellows, under pain of ignominy and fines, that they do not show any natural work or thing, adorned or swelling, but only pure as it is, without all affectation of strangeness. (3, 164)

Though recent criticism has peddled a caricature of the Lord Chancellor as the sinister architect of our modern technocracy and its ensuing ecological crisis,[20] his later writings often express reservations about technology and preach a moderate pace for its advance. In a piece added to the final edition of his *Essays*, 'On Innovations', Bacon advises that new inventions 'be held for a suspect' (6, 434); necessity, not novelty, should determine whether they find widespread acceptance in society at large. Bacon voices his misgivings even more loudly in *De Sapientia Veterum*, where he interprets Daedalus as a personification of mechanical philosophy and reflects on some of the dubious devices credited to the Greek inventor: the 'machine' that enabled Pasphinae to copulate with a bull, the Minotaur's labyrinth, Icarus's wings. For Bacon the myth offers a cautionary fable about 'the unlawful contrivances of art' (6, 735). While he concedes that technology has brought numerous benefits for mankind, he concludes with a doleful reminder that 'out of the same fountain come instruments of lust, and also instruments of death [...]. The most exquisite poisons, also guns, and such like engines of destruction, are the fruits of mechanical invention' (6, 735). This sobering observation qualifies the zeal for technology that animates *The*

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[19] Boesky A., *Founding Fictions: Utopias in Early Modern England* (Athens: 1996) 57.
[20] Merchant C., *Death of Nature.*

New Atlantis. Further evidence that Bacon's passion for technology had cooled can be inferred from the *Valerius Terminus.* The heading for the tenth chapter of the work announces that it will contain 'an enumeration of inventions already discovered and in use' (3, 324). The text exists in a fragmented state, leaving its Victorian editors to conclude that Bacon intended to insert the inventory at a later date. However instead of the promised catalogue he scrawls only a final sentence in the margins of the manuscript rebuking the impostors and charlatans who have deluded the public with tales of fabulous devices 'differing as much from truth in nature as Caesar's Commentaries differeth from the acts of King Arthur' (3, 234). The addendum captures Bacon's creeping distrust of technology as a basis for establishing certainty in the natural sciences. Just as Bacon himself scrambles the categories of history and fiction by appending *New Atlantis* to his scientific writings, his warnings against the abuse of technology undercut his claims that it will facilitate an impartial, universal knowledge of nature.

Compared with the Royal Society's mania for technology, such proclamations would have struck Cavendish as exceedingly sensible and cautious. Rather than conceiving of *The Blazing World* as a searing rebuttal to Bacon, her utopia may represent an attempt to dispute his real legacy. Their mutual interest in uncovering 'natural truths' and their concern with the problems 'hermaphroditical art' posed to this project should remind us to beware of oversimplifying the correlations between gender and epistemology in early modern science.

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PART III

METAPHORIC MODELS

THE ROLE OF METAPHORS IN WILLIAM HARVEY'S THOUGHT

Jarmo Pulkkinen

1. *Introduction*

In this paper, I shall discuss William Harvey's (1578–1647) use of metaphor in two of his works. The first, the *Exercitatio anatomica de motu cordis et sanguinis in animalibus* (1628), is one of the greatest achievements in the history of science, for it introduces the doctrine of the circulation of the blood. The second is the *De motu locali animalium* (c. 1628), that is, Harvey's incomplete manuscript on animal movement and the structure of muscles in general. The *De motu locali* has received only little attention among historians of science, most likely for its lack of originality, being as it is chiefly a compilation of the views of Aristotle, Galen, and Harvey's teacher Hieronymus Fabricius of Aquapendente (1537–1619), together with some commentaries. Moreover, it was a failure. Harvey never published the manuscript.

However, I still believe that the study of *De motu locali* can provide some interesting historical insights. In particular, it provides further information about Harvey's use of metaphors. Moreover, I believe that the failure of the *De motu locali* throws some additional light on the success of the *De motu cordis*, that is, on the discovery of the circulation of blood. I shall argue that Harvey's choice of source domain for his metaphors was critical to his success in the *De motu cordis*, as well as to his failure in the *De motu locali*.

2. *The Functions of Metaphor*

Although metaphors have been studied for over 2000 years, a precise definition of the word has been notoriously difficult to formulate. Daniela Bailer-Jones offers the following definition: 'A metaphor is a linguistic expression in which at least one part of the expression is transferred […] from one domain of application (source domain), where it is common, to another (target domain) in which it is unusual, or was probably

unusual at an earlier time when it might have been new.'[1] However, this definition does not specify the relationship between the source domain and the target domain. Dedre Gentner has distinguished among three possibilities: First, metaphors can be relational comparisons, that is, the source domain and the target domain share a common relational structure. For example, "the atom is a solar system". Second, metaphors can be attribute comparisons, for example "Mike is a giraffe" conveys that Mike and giraffe share the attribute "tall". The third class of metaphors consists of such complex metaphors as "the voice of your eyes is deeper than all the roses". These metaphors are characterised by many inter-weaving connections without a clear way of deciding exactly how the source predicates should attach to the target.[2]

According to traditional views, metaphors are rhetorical and poetic devices. However, nowadays it is widely accepted that some metaphors can be used as "cognitive instruments".[3] According to Max Black, metaphors can be employed as instruments for drawing implications grounded in analogies of structure between two subjects belonging to different domains.[4] Consequently, metaphors have two important roles in scientific thought. First, they introduce terminology where none previously existed. It is noteworthy that concepts are not introduced one at a time but as frameworks of concepts. In other words, metaphors give us a structured conceptual framework for explaining and understanding an unfamiliar or novel natural phenomenon.

At the same time, metaphors can sometimes contribute to the substance and structure of philosophical and scientific theories. One could say that the unknown is "seen through" the known. According to Black, a metaphor suppresses some details, emphasises others – in short, it organizes our view of the unknown thing or phenomenon.[5] The second role of metaphor is to produce new topics for research. In other words, statements concerning the source domain can be translated into hypotheses about the target domain. With the help of metaphors scientists can formulate hypotheses, which can be tested empirically and

[1] Bailer-Jones D., "Models, Metaphors and Analogies", in Machamer P. – Silberstein M. (eds.), *The Blackwell Guide to the Philosophy of Science* (Oxford: 2002) 114.

[2] Gentner D., "Viewing Metaphor as Analogy", in ed. D.H. Helman, *Analogical Reasoning* (Dordrecht: 1988) 171–173.

[3] Black M., "More About Metaphor", in Ortony A. (ed.), *Metaphor and Thought* (Cambridge: 1979) 39.

[4] Black M., "More About Metaphor" 32.

[5] Black M., "Metaphor", in Black M., *Models and Metaphors* (Ithaca-London: 1962) 41.

experimentally. This has been characteristic of the use of metaphors in modern experimental science.

When we use metaphors as cognitive instruments, we are attempting to understand and explain the unknown (i.e. target domain) with the known (i.e. source domain). In this respect, the choice of source domain is significant. Metaphors derived from different source domains provide different kinds of conceptual frameworks. First, the source domain can be the physical world, that is, living entities and nonliving material objects. For example, "electron is a wave" in modern physics or "tree of life" in the theory of evolution. This kind of metaphorical use is very popular in philosophy and science.

Second, the source domain can be the world of mental states, that is, the world of subjective or personal experiences. This kind of metaphor is uncommon. However, some examples can be found. In Empedocles' philosophy all matter in the cosmos is made of air, water, earth, and fire, but he added two diametrically opposed cosmic forces. "Love" brings order into the cosmos by creating something new. "Strife" is the dividing force that separates and destroys things. In other words, the cosmos is like an individual psyche suffering from constant mood changes.

Third, the source domain can be the realm of social relations, institutions, and structures. In Plato's *Theaetetus*, Socrates helps to "give birth" to wisdom in others. In the same way as an ordinary midwife guides the soon-to-be mother through a complicated process of childbirth, a "philosophical midwife" directs the pupil through the difficult process of philosophical education. Both processes involve crucial moments at which all can be lost without the intervention of the midwife.

Next, the source domain can be the abstract product of the human mind, that is, a different kind of information and symbol systems. In *Timaeus*, Plato attempts to explain the interaction among four elements with help of geometrical metaphors. He argues that the particles of air, water, earth, and fire are constructed from regular solids. A particle of fire is a tetrahedron, a particle of air an octahedron, a particle of water an icosahedron, and a particle of earth a cube. The shapes and sizes of these regular geometrical solids are linked with their physical qualities: for example, the destructive power of a fire pyramid is connected to its sharp angles and sides. The notion "DNA is a code" changed fundamentally the way life was understood in the 20th century.

Finally, the source domain can be from technology, for example, "mind is a digital computer". Technology has been one of the most

important source domains of "insightful" metaphors. In particular, I want to emphasise the role of artefacts, that is, any object made, modified, or used by people. First, we have a very exhaustive knowledge of artefacts, that is, a maker's knowledge. Consequently, they are very helpful in the attempt to explain the unknown through the known. Second, the structure and function of artefacts is unambiguous. Thus, they provide a clearly structured conceptual framework. Third, as technology advances, new technological devices are constantly invented. These devices can be used as novel and possibly insightful metaphors in science.

Many different kinds of artefacts exist. Carl Mitcham has distinguished between utensils (e.g. baskets and pots), clothes, structures (e.g. houses), apparatus (e.g. dye vats and brick kilns), utilities (e.g. roads and reservoirs), toys, tools of doing or performing (e.g. numbers and musical instruments), objects of art or religion, tools, machines, and automata.[6] In the history of science, some of these artefacts have been more important as metaphors than others have been. In particular, I want to emphasise the importance of machines and automata. Both machines and automata may be described in terms of mathematical relations among their moving and stationary mechanical parts. When using a machine or automaton metaphor, these mathematical relations can be transferred from the source domain of technology to the target domain of the physical world. As a result, the natural phenomena can be subjected to quantitative description.

In fact, it was no accident that the rise of mechanical philosophy was intimately linked to the rise of experimental science and the so-called "quantitative method". In mechanical philosophy, nature is like a machine. Thus, natural phenomena can be explained in terms of hidden mechanisms, and the structure and function of these "natural mechanisms" can be described in quantitative terms.[7]

[6] Mitcham C., *Thinking Through Technology: The Path Between Engineering and Philosophy* (Chicago-London: 1994) 162–163.

[7] Craver C. – Darden L., "Introduction", *Studies in History and Philosophy of Biological and Biomedical Sciences* 36 (2005) 236.

3. *Trends in Harvey Scholarship*

There have been two main trends in Harvey scholarship. On the one hand, Harvey's work has been seen in the context of mechanical philosophy. This approach has been characteristic of the general histories of the scientific revolution.[8] Representatives of this viewpoint have emphasised the role of the quantitative method and the "pump" metaphor, that is, the analogies between the mechanism of heart and a hydraulic pump in Harvey's thought. On the other hand, it has been argued that Harvey's research was guided by a vitalistic conception akin to the Aristotelian tradition. The latter view is nowadays the dominant one, and any difference of opinion concerns the exact nature of Harvey's Aristotelianism. However, all Harvey scholars agree on the special importance of anatomical observations and experiment in Harvey's work. Moreover, it is generally accepted that Harvey relied on the results of his predecessors.

4. *Traditional View of the Function of the Heart and the Movement of Blood*

The introduction of *De motu cordis* is devoted to the critique of Galenic physiology. Harvey states that 'it is of considerable importance first to set forth those things which have been published by others, and to take notice of the things which have been commonly said and taught, so that what has been rightly spoken may be confirmed and what is false corrected.'[9] He begins with the rejection of Fabricius' book *De respiratione*, which had developed the Galenic notion that heart and arteries have a respiratory function.[10]

Next, Harvey criticises the notion that arteries do not contain blood but pneuma. To this purpose, he compares the views of Erasistratus and Galen. Greek anatomist Erasistratus (c. 310–250 BC) was probably the first to discover the coordinated function of all main valves of the heart. He regarded these valves as mechanisms for maintaining the

[8] Westfall R., *The Construction of Modern Science* (Cambridge: 1979) 90–91; Hall A.R. *The Revolution in Science 1500–1750* (London-New York: 1989) 161–162.

[9] William Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures*, translated with an introduction and notes by Gweneth Whitteridge (Oxford: 1976) 10.

[10] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 10.

flow in one direction. Consequently, he considered the heart as a kind of two-stroke pump (i.e. combined suction and force) equipped with unidirectional valves (since it is designed to move two different fluids, blood and pneuma, simultaneously).[11] On the one hand, the systole of the right ventricle pumped blood into the veins, through which it was distributed throughout the body. On the other hand, the systole of the left ventricle pumped pneuma into the arteries.[12]

Since Erasistratus believed that there was only pneuma in the arteries, he had to explain the undeniable presence of blood in the arteries whenever they were perforated. He invoked the principle of *horror vacui*. When an artery was severed, the pneuma was so subtle that it escaped unperceived. Thus, the vacuum that was created was immediately filled by blood from the veins through certain fine capillaries that were normally closed. It is generally believed that this ingenious hypothesis survived for almost four and a half centuries until Galen refuted it by careful experiments.[13]

Harvey naturally agreed with Galen's critique of Erasistratus. According to Harvey, 'that blood is contained in the arteries, and that the arteries carry blood only, is obvious from Galen's experiment'.[14] Galen's procedure was to bind the artery at both ends with fine cords and slit it open lengthwise down the middle.[15] One could then observe

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[11] Lonie I.M., "The Paradoxical Text 'On the Heart', Part II" *Medical History* 17 (1973) 138. Lonie suggested that Erasistratus might have based his conception of the functioning of the heart on a technological metaphor. Should this be the case, Lonie's theory would point to a rare instance in which a Greek scientist used a technological metaphor. Greek engineer Ctesibus lived in Alexandria in the reign of Ptolemy II (283–247 BC) and was a contemporary and fellow-citizen of Erasistratus. Ctesibus invented the force pump. It had two vertical cylinders that alternate intake and output to deliver a constant jet of water. Although Erasistratus might have seen well the pump in operation, we have no way of knowing if he used it as a metaphor in his scientific thought. Yet it can be argued that the Ctesibian machine and Erasistratus' four-valve heart were the index of a particular way of thinking, that is, of seeing things in terms of a functional machine, in which part and function could not be separated from each other and considered in isolation (Lonie I.M. "The Paradoxical Text 'On the Heart', Part II" 138–139).

[12] Vegetti M., "Between Knowledge and Practice: Hellenistic Medicine", in M. Grmek (ed.), *Western Medical Thought from Antiquity to the Middle Ages* (Cambridge, Massachusetts-London: 1998) 97.

[13] Longrigg J., *Greek Rational Medicine: Philosophy and Medicine from Alcmaeon to the Alexandrians* (London-New York: 1993) 210.

[14] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 13.

[15] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 13.

that the artery was always found to be full of blood. However, in other respects, Harvey disagreed with Galen.

In Galen's view, there were two systems for the formation and movement of blood: one consisting of the liver and the veins; the other, the heart and the arteries. Consequently, there were two types of blood, venous and arterial. According to the Galenic consensus, the two types of blood ran parallel by virtue of the repulsive faculty of the liver and the heart and by virtue of the attractive force of the parts of the body that required them. Each system was represented by a form of pneuma, a substance that was considered essential to all life.[16]

Galen adopted the common Greek notion that blood was formed in the liver from ingested food. The liver also formed natural spirits from this nutriment. From the liver, venous blood and natural spirits spread through the veins to all parts of the body, where they were used up as nourishment. A portion of the venous blood was transmitted from the liver to the right ventricle of the heart through the inferior vena cava. However, as there was no obvious anatomical pathway between the two ventricles of the heart, Galen theorized that blood seeped through invisibly small pores in the septum of the heart, out of the right ventricle and into the left. At the same time, air was moved down from the lungs through the pulmonary vein to the right ventricle of the heart. From blood and air, there arose in the left ventricle the finer vital spirit, which distributed heat and vitality throughout the body via the arterial system.[17]

In the introduction of *De motu cordis* Harvey has two main arguments against the Galenic theory. First, he rejects the theory that blood seeps through the septum between ventricles. Harvey cries out: 'But, in God's truth, there are no such pores, nor can any be demonstrated'.[18] He points out that 'the substance of the septum of the heart is thicker and more compact than any part of the body, except the bones and sinews.'[19]

[16] Pagel W., *William Harvey's Biological Ideas* (Basel-New York: 1967) 132; Gourevitch D. "The Paths of Knowledge: Medicine in the Roman World", in M. Grmek (ed.), *Western Medical Thought from Antiquity to the Middle Ages* (Cambridge, Massachusetts-London: 1998) 131.

[17] Pagel W., *William Harvey's Biological Ideas* 132; French R. *William Harvey's Natural Philosophy* (Cambridge: 1994) 99; Fuchs T., *The Mechanization of the Heart: Harvey and Descartes* (Rochester: 2001) 25.

[18] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 20.

[19] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 20.

Moreover, he argues that if there were holes, how was it possible that these holes would allow only one-way flow. Why should one not rather believe that 'the right ventricle draws spirits from the left than that the left, through the same holes, draws blood from the right?'[20]

Harvey's second argument is directed against Galen's conception of the function of the mitral valve between the left atrium and the left ventricle of the heart. In the Galenic theory, the mitral valve permitted air to move from the atrium into the ventricle, but prevented the reflux of air into the atrium. However, Galenic theory also stated that the lungs needed their share of newly produced arterial blood, and the concoction of blood in the left ventricle produced sooty wastes that were to be expelled through the pulmonary veins.[21] Harvey finds this unconvincing. First, if the mitral valves did not hinder the return of sooty wastes to the lungs, how could they prevent the return of air? The same applies to the movement of arterial blood: 'Good God! How do the mitral valves impede the return of air and not of blood?'[22]

Harvey was not the first to criticise the Galenic theory of the function of the heart and the movement of blood. Pulmonary circulation, in particular, presented problems to Galenic theory. Galen had only a vague notion of the pulmonary transit of venous blood. The earliest known account of pulmonary circulation was given by an Arab physician, Ibn an-Nafis (c. 1210–1288). According to an-Nafis, the thick septum of the heart did not have pores. Instead, the blood from the right ventricle flowed through the pulmonary artery to the lung, there to disperse inside the substance of the lung, and to mix with air. Then the pulmonary vein carried the mixture of blood and air to the left ventricle, where the vital spirit was produced.[23] It is possible, but usually thought to be improbable, that the Latin West had access to Ibn an-Nafis' description of the lesser circulation. The Arabic text of Ibn an-Nafis was available in Venice, but it was not discovered and translated until 1924.[24]

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[20] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 20.

[21] French R., *William Harvey's Natural Philosophy* 99.

[22] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 18.

[23] Iskandar, A.Z., "Ibn an-Nafis," in Gillispie C. (ed.), *Dictionary of Scientific Biography* Volume 9 (New York: 1974) 603.

[24] Mason S., "Religious Reform and the Pulmonary Transit of the Blood" *History of Science* 41 (2003) 465.

Michael Servetus (1511–1553), a Spanish physician, was the first European to describe pulmonary circulation. However, his description appeared in a theological work, *Christianismi Restitutio* (1553), not in a treatise devoted to anatomy.[25] Moreover, although his observations were based on genuine anatomical studies, they were designed to support his heretical religious beliefs.[26] According to Servetus, God was immanent throughout Creation, while the divine spirit continuously sustained and animated all creatures. In humans, the divine spirit was drawn into the lungs through respiration. In contrast to Galen, Servetus argued that blood flowed from the right ventricle to the left ventricle via the lungs. In the lungs, the dark venous blood was 'spiritualized' into bright arterial blood. The regenerated arterial blood then passed through the pulmonary vein to the left ventricle of the heart.[27]

Servetus was burned at the stake for heresy in Geneva in October 1553, shortly after the publication of the *Christianismi Restitutio*. In 1556, pulmonary circulation was described by the Spaniard physician Juan de Valverde (c. 1520–1588). In 1559, Valverde's teacher, Realdo Colombo (c. 1516–1559), reported his vivisection evidence for pulmonary circulation in his *De re anatomica*.[28] Neither Valverde nor Colombo made reference to Servetus. However, it has been argued that they may have had knowledge of Servetus' anatomical and physiological theories.[29] Harvey was familiar with Colombo's *De re anatomica*. In *De motu cordis* Harvey refers to Colombo's views on the pulmonary transit, and it seems probable that Harvey relied on Colombo's results to some degree.[30]

However, Roger French maintains that although Harvey adopted Colombo's notion that blood crossed the lungs, this should not be regarded as a sort of "contribution" or stepping-stone to Harvey's final discovery of circulation. Colombo's main aim was to prove that spirit was generated in the lungs, not in the left ventricle of the heart, as in the Galenic theory. It was a minor corollary that the blood he found in the pulmonary vein had come across the lungs from the pulmonary artery.

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[25] Pagel W., *William Harvey's Biological Ideas* 137.

[26] Pagel W., *William Harvey's Biological Ideas* 145.

[27] Mason S., "Religious Reform and the Pulmonary Transit of the Blood" 463; Pagel W. *William Harvey's Biological Ideas* 145.

[28] Mason S., "Religious Reform and the Pulmonary Transit of the Blood" 465.

[29] Pagel W., *William Harvey's Biological Ideas* 166; Mason S. "Religious Reform and the Pulmonary Transit of the Blood" 464.

[30] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 17 and 67.

For Harvey, the flow of blood across the lungs was also a secondary corollary, not the point at issue. His main aim was to discover a pulse in the pulmonary artery to prove that pulsation was due to the forceful injection of blood from the heart into the pulmonary artery.[31]

Harvey concludes the introduction of his book with a statement that what has been said to date concerning the function of the heart and the movement of blood seems 'either improbable or obscure or impossible'.[32] Thus, Harvey continues, 'it will be profitable to search more deeply into the business and to contemplate the motions of the heart and arteries not only in man, but also in all other creatures that have a heart, and likewise by the frequent dissections of living things and by many anatomies of the dead, to discern and search out the truth'.[33]

5. *The Role of Experimental Observation*

All Harvey scholars agree on the special importance of anatomical observation and experiments in Harvey's work. Harvey received excellent training in dissection and vivisection. After graduating from Cambridge, he continued his medical education at the University of Padua, which was the foremost centre of medical research in Europe at that time. At Padua, Harvey studied under the eminent anatomist Hieronymus Fabricius of Aquapendente (1537–1619), whose teaching was based on public dissections. In 1594, Fabricius constructed the first permanent anatomical theatre designed to permit as many students as possible to observe the dissection.[34] Later, in 1615, Harvey was appointed to the post of Lumleian lecturer at the Royal College of Physicians. Lumleian lectures were followed by a five-day dissection of a human body in the winter that followed the year's lectures. Starting in 1616, Harvey held the lectures for the next 28 years.[35] However, his investigations of the function of the heart and blood were mostly based on

[31] French R., *William Harvey's Natural Philosophy* 82–83.

[32] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 21.

[33] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 22.

[34] French R., *William Harvey's Natural Philosophy* 66; Keynes G. *The Life of William Harvey* (Oxford: 1978) 25.

[35] French R., *William Harvey's Natural Philosophy* 71–72.

animal vivisection. The use of live animals provided the opportunity to observe the heart in action.

Harvey also emphasises the importance of dissection and vivisection in his published writings, stating that his aim in *De motu cordis* was to learn and teach anatomy not 'from books or from the maxims of philosophers, but from dissections and from the fabric of Nature herself'.[36] Moreover, dissections of living animals offered him the method of discovering 'the use and benefits of the motion of the heart through actual inspection with my own eyes, and not from books and the writings of other men'.[37]

In the preface to *De generatione animalium* (1651), Harvey deals with the same subject on a more general level, that is, he emphasises the role of empirical observation in scientific investigation. In his view, 'in every discipline, diligent observation is a prerequisite and the senses themselves must frequently be consulted'.[38] Without careful observation, 'we make judgments entirely on phantoms and apparitions inhabiting our minds'.[39] In this respect, Harvey's views are similar to those of Francis Bacon (1561–1626). Harvey knew Bacon personally, having treated Bacon during one or more of his illnesses.[40] Harvey had probably also read Bacon's works and even uses Bacon's terminology on two occasions. First, in the preface to *De generatione animalium*, he refers to Bacon's "idols of the theatre" while criticizing 'sophisters and half-knowing men' who merely read the words of 'Authors' and do not use the aid of their own senses. In Harvey's opinion, they conceive in their own minds nothing but 'deceitful eidola and vain fancies and never true Ideas'.[41] Second, in the 25th chapter of *De generatione animalium*, Harvey employs Bacon's notion of 'vintage'.[42]

Although Harvey and Bacon agreed on the importance of experimental observation at a general level, there were important differences between their views. Bacon's low opinion of Aristotelian philosophy is

[36] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 7.
[37] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 29.
[38] William Harvey, *Disputations Touching the Generation of Animals*, translated with introduction and notes by Gweneth Whitteridge (Oxford: 1981) 13.
[39] Harvey, *Disputations Touching the Generation of Animals* 13.
[40] Keynes G., *The Life of William Harvey* 157.
[41] Harvey, *Disputations Touching the Generation of Animals* 16.
[42] Harvey, *Disputations Touching the Generation of Animals* 134.

well known. In Bacon's view, the philosophy of Aristotle was 'only strong for disputations and contentions, but barren of the production of works for the benefit of mankind'.[43] Yet, Harvey did not share Bacon's dislike of Aristotle. On the contrary, Harvey's natural philosophy took Aristotle as its main source.[44] While Harvey had been exposed to Aristotelianism during his undergraduate years in Cambridge, his stay in Padua was crucial in this respect. There, Harvey adopted the Aristotelian approach to the study of nature from his teacher Fabricius who emphasised the importance of the naturalistic elements of Aristotle's philosophy. According to John Aubrey's account of Harvey's life, Harvey did not hold Bacon's scientific work in high regard: 'He had been Physitian to the Lord Ch. Bacon, whom he esteemed much for his witt & style, but would not allow him to be a great philosopher. 'He writes Philosophy like a Lord Chancellor,' he said to me speaking in derision'.[45]

6. *Observation vs. Theory*

Philosophers of science today more or less agree there is no such thing as "pure observation". To be meaningful, observations and experiments must be interpreted and, in this sense, are always "theory-laden". In my view, some Harvey scholars have overemphasised the role of experimental observation in his work. Gweneth Whitteridge, for example, writes that 'it was the facts assembled before him [Harvey] that dictated the hypothesis of circular movement'.[46] Yet, I would emphasise that the practice of dissection and vivisection is always prompted and directed by theoretical assumptions. This also applies to Harvey's anatomical and physiological work.

In his history of Greek science, G.E.R. Lloyd talks about the difficulties faced by the earliest Greek researchers in anatomy and physiology. In Lloyd's view, for a dissection or vivisection to be performed successfully, it requires 'not only patience, attention to detail and practical skill, but also and more importantly a clear conception of what to

[43] Rossi P., *Francis Bacon: From Magic to Science* (London: 1968) 36.
[44] French R., *William Harvey's Natural Philosophy* 51.
[45] Keynes G., *The Life of William Harvey* 433.
[46] Whitteridge G., *William Harvey and the Circulation of the Blood* (London: 1971) 128.

look for.'[47] It is not enough to carry out a dissection, but one must also understand what one sees. Thus, the fruitful practice of dissection and vivisection depends on a complex interaction of theories and observations.[48] Although Lloyd speaks only about ancient Greek anatomy and physiology, his observations on the nature of dissection and vivisection have a more general validity. Harvey also acknowledged the difficulties of dissection and vivisection, even as he emphasised the importance of experimental observation. Chapter one of *De motu cordis* begins with Harvey's account of his problems with the practice of dissection:

> When I first applied my mind to observation from the many dissections of living creatures as they came to hand, that by that means I might find out the use and benefits of the motion of the heart through actual inspection with my own eyes, and not from books and the writings of other men, I straightway found it a thing hard to be obtained and full of difficulty, so that I almost believed with Fracastorius that the motion of the heart was known to God alone.[49]

Harvey goes on to say he was 'much troubled in mind and did not know what to think, whether what myself had concluded or whether to believe others'.[50] Thus, the discovery of the circulation of blood had to wait until Harvey first learned to ask the right questions. In this respect, Harvey's work was made more difficult by the presence of the Galenic tradition. The Galenic theory seemed to provide a satisfactory description of the functioning of the heart and the movement of blood. As such, it presented a powerful obstacle both to the discovery and the acceptance of the circulation theory. In the beginning of Chapter 8, Harvey expresses the fear that since his discoveries were 'so new and unheard', he would have all men as enemies. According to Harvey, 'so much does custom and doctrine once absorbed and deeply rooted, like second nature, weigh with all men and the revered appearance of antiquity constrain them'.[51]

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[47] Lloyd G.E.R., *Magic, Reason and Experience: Studies in the Origin and Development of Greek Science* (Cambridge: 1979) 161.

[48] Lloyd G.E.R., *Magic, Reason and Experience* 168.

[49] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 29.

[50] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 29.

[51] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 74.

Thus, Harvey's scientific work and his discovery of the circulation of blood cannot solely be attributed to his anatomical experiments. He could have interpreted his observations in the same way his predecessors did, i.e., in the framework of the Galenic tradition. Instead, Harvey found a novel conceptual framework in which to interpret his observations, and revolutionized anatomy and physiology with his discovery of the circulation of blood. In this respect, Harvey's use of metaphors is important.

7. *The Macrocosm Metaphor*

Some historians of science have argued that the macrocosm metaphor provided Harvey with the required framework.[52] Thus, it would seem that one of the most important discoveries of modern anatomy and physiology is profoundly indebted to what are, from today's perspective, "pre-scientific" presuppositions and ideas.[53] The idea connected with the notions of microcosm and macrocosm is the belief that an identity exists between the universe and the individual human being. The macrocosm is the universe as a whole whose parts are thought of as analogous to the parts of a human being. The microcosm is an individual human being whose parts are thought of as analogous to the parts of the larger universe.[54] The microcosm metaphor amounts to anthropomorphism, that is, to the attribution of human characteristics to nonhuman organisms and nonliving objects. In the macrocosm metaphor, the source domain is the nonliving physical world and the target domain, an individual organism.

The idea of the microcosm appears in pre-Socratic philosophy. Plato offers the first detailed discussion of the idea in *Philebus*. The Greek expression for "microcosm" occurs for the first time in Aristotle's *Physics*. In late antiquity, the belief in the identity between microcosm and macrocosm had an important role in the thought of the Stoics and of

[52] Pagel W., *William Harvey's Biological Ideas* 82–83; Bates D., "Harvey's Account of his 'Discovery'" *Medical History* 36 (1992) 361–378; Gregory A., "Harvey, Aristotle and the Weather Cycle" *Studies in History and Philosophy of Biological and Biomedical Sciences* 32 (2001) 153–168.

[53] Fuchs T., *The Mechanization of the Heart* 2.

[54] Boas G., "Macrocosm and Microcosm", in P. Wiener (ed.), *The Dictionary of the History of Ideas: Studies of Selected Pivotal Ideas* Volume 3 (New York: 1973) 126.

Plotinus.[55] Renaissance speculation on the microcosm focussed on the idea that the inner experience of human nature supplies a direct route to the knowledge of reality. These occult versions of the microcosm idea arose from to the rediscovery of the *Corpus Hermeticum* and other mystical texts of late antiquity.

Robert Fludd (1574–1637), Paracelsian physician, Rosicrucian, and mystical cosmologist has sometimes been presented as a possible source of Harvey's macrocosm metaphor.[56] Fludd was Harvey's friend and was present at many of his dissections. In 1623, Fludd published the *Anatomiae amphitheatrum*, which contained a chapter on the mystical anatomy of blood. In it, Fludd discussed the heart and blood in terms of cosmic analogies, ascribing to blood a circular motion analogous to that of the sun.[57] Later, in 1631, Fludd was the first to accept Harvey's doctrine of the circulation of blood in print. However, Fludd was not convinced by Harvey's quantitative experiments. He endorsed Harvey's discovery because, in his view, it confirmed the influence of the macrocosm on the microcosm.[58]

Harvey used the macrocosm metaphor in both the *De motu cordis* and the *De motu locali*. In *De motu locali*, Harvey compared the animal body to the Pythagorean concept of the universe:

> Nature performs her works in animals by the power of the muscles and attains her end by means of rhythm and harmony. Thus Aristotle says. It will appear that through godlike power truly in the heaven there is a pursuit of the delectable and the lovable by harmony and rhythm of movement of which we have no more perception than a dog has of music.[59]

The scheme of correspondence between the animal body and the cosmos can be presented as follows:

Cosmos	Animal body
Celestial bodies	Muscles

[55] Levy D., "Macrocosm and Microcosm", in Edwards P., *Encyclopedia of Philosophy* Volume 5 (New York: 1967), 123.
[56] Pagel W., *William Harvey's Biological Ideas* (Basel-New York: 1967) 119.
[57] French R., *William Harvey's Natural Philosophy* 128; Pagel W. *William Harvey's Biological Ideas* 118–119.
[58] Pagel W., *William Harvey's Biological Ideas* 115.
[59] William Harvey, *De motu locali animalium 1627*, edited, translated and introduced by G. Whitteridge (Cambridge: 1959), 143.

The main concepts of the "cosmic harmony" metaphor are rhythm and harmony. According to the Pythagorean concept of cosmic harmony, the cosmos is put together by means of laws of musical harmony. Thus, the cosmos produces through the motion of the celestial bodies, rhythm and harmony.[60] Harvey claims that, similarly, the diverse movements of muscles produce the harmonious action of the animal body:

> Just as divine Nature pursues an architectonic end making of diverse things one, of different things the same, by composing discords and making opposition to harmonize, so through diverse movements and uses and employments of the muscles are effected the works and actions of the body and of the parts. And so the actions are performed to effect movement by using the operations of the muscles in two ways: harmony and rhythm.[61]

In *De motu cordis*, Harvey refers to the notions of microcosm and macrocosm in three instances. First, in the dedication to Charles I, Harvey makes a comparison between the heart, the king, and the sun:

> The Heart of all creatures is the foundation of their life, the Prince of all their parts, the sun of their microcosm, that on which all growth depends and from whence all strength and vigor flows. In like manner, the King is the foundation of his kingdom, the sun of his microcosm, the heart of his commonwealth, from whom all power flows and mercy proceeds.[62]

Moreover, in Chapter 17, he says that 'the heart is like the Prince in the Commonwealth in whose person lies the first and supreme power, governs all things elsewhere, and from it as from its origin and foundation in the living creature all power derives and on it does depend'.[63]

Harvey's comparison of the role of a king and the function of the heart, however, is unoriginal. It is a version of the ancient "body politic" metaphor in which state or society is understood and explained by comparison with the parts and relationships of a human body.[64] The body politic metaphor had already appeared in Plato's and Aristotle's

[60] Haar J., "Pythagorean Harmony of the Universe", in Wiener P. (ed.), *The Dictionary of the History of Ideas: Studies of Selected Pivotal Ideas* Volume 4 (New York: 1973) 39.

[61] Harvey, *De motu locali animalium* 143.

[62] Harvey, *An Anatomical Disputation concerning the Movement of the Heart and the Blood in Living Creatures* 3.

[63] Harvey, *An Anatomical Disputation concerning the Movement of the Heart and the Blood in Living Creatures* 130.

[64] On the body politic metaphor, see D. Hale, *The Body Politic: A Political Metaphor in Renaissance Literature* (The Hague: 1971).

writings.[65] It had been developed substantially in the Middle Ages. A famous example of the metaphor can be found in John of Salisbury's *Policraticus* (1159). John of Salisbury presented a detailed scheme of correspondence between the source domain of human body and the target domain of human society. For example, the soul corresponds to the ministers of God, the head to the prince, the heart to the senate, the officials and the soldiers to the hands, and so on.[66] The metaphor flourished in the Renaissance, but its popularity faded in the 17th century.

Harvey's second reference is much more important. In the opening lines of Chapter 8, Harvey explains how he first noticed that the amount of blood the heart transmitted in a short period was so large and could cause problems.[67] The juice of the food that has been eaten would not suffice to supply the required amount of blood. Moreover, the veins would be empty whereas the arteries would rupture from the overflow of blood. According to Harvey, he soon realized that the only possible explanation was that in some way or another, blood flows from the arteries to the veins and returns to the heart.[68] After this, Harvey adds: 'I began to bethink myself whether it might not have a kind of movement as it were in a circle. And this I afterwards found to be true.'[69]

Harvey continues by referring to Aristotle: 'We may call this motion circular in the same way in which Aristotle says that the air and the rain imitate the circular motion of the heavens.'[70] In Aristotle's philosophy, circular motion is perfect compared to all other kinds, because it is the only motion, which is continuous. As a result, the perfect circular motion of the stars is imitated by the phenomena in the sublunary world: 'For when water is transformed into air, air into fire, and fire back into water, we say the coming-to-be has completed the circle,

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[65] For example, Aristotle uses it in *De motu animalium* (703a29–b2).

[66] Hale D., *The Body Politic* 39.

[67] The interpretation of this passage has presented great difficulties to Harvey scholars. In particular, one crucial sentence is very long, rambling and awkward. The most detailed analysis of the situation has been made by Don Bates (Bates D., "Harvey's Account").

[68] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 75.

[69] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 75.

[70] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 75.

because it reverts again to the beginning'.[71] As Harvey sees it, Aristotle says that moist earth is warmed by the heat of the sun and gives off vapors, which are condensed and descend again as rain and wet the earth.[72] By this means, the cycle of life is created, that is, 'the growth of trees, the ripening of fruits, the birth of animals, the nurturing and the prime and decay of all things'.[73] In other words, 'the heart is the first principle of life and the sun of the microcosm'.[74] In the same way that the sun is the source of all life on earth, the heart also warms and activates the body as a whole. In this respect, Harvey follows the example of Aristotle, who upheld the heart as the origin and supreme part of the organism.[75]

However, in Chapter 71 of *De generatione*, Harvey uses the same metaphor, but instead of comparing the sun to the heart, he compares it to the blood. In fact, Harvey makes the connection between the blood and the heat without mentioning the heart at all. Harvey says that in so far as the blood is spirit 'it is hearth, the goddess Vesta, the household deity, innate heat, the sun of the microcosm, Plato's fire, not because like ordinary fire it shines, burns and destroys, but because it preserves and nourishes itself and grows by its wavering and perpetual motion'.[76] Moreover, the blood travels 'swiftly through the whole body and nourishes, cherishes and keeps alive all the parts (which it does itself fashion and adjoin to itself), truly no otherwise than the superior luminaries, the Sun and the Moon, give life to this inferior world by their continuous circular motions'.[77] As Pagel points out, the difference between the *De motu cordis* and the *De generatione* can be explained with reference to the different main subjects of the two books. In *De motu cordis*, Harvey emphasises the central role of the heart only when speaking of the circulation of the blood. At the same time, he was fully aware that the heart did not hold this central role in the development of the embryo.[78]

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[71] Aristotle, "On Generation and Corruption", in J. Barnes (ed.), *The Complete Works of Aristotle* (Princeton: 1984) 337a4–6.

[72] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 75.

[73] Aristotle, "On Generation and Corruption" 399 a28–29.

[74] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 76.

[75] Pagel W., *William Harvey's Biological Ideas* 43.

[76] Harvey, *Disputations Touching the Generation of Animals* 381–382.

[77] Harvey, *Disputations Touching the Generation of Animals* 381–382.

[78] Pagel W., *William Harvey's Biological Ideas* 342–343.

Harvey's "weather cycle" metaphor, too, was unoriginal. For example, in antiquity Seneca presented a detailed comparison between the human body and the earth. According to Seneca, the earth 'is much like the system of our bodies in which there are both veins (receptacles for blood) and arteries (receptacles for air)'. Moreover, 'nature fashioned these routes so like human bodies that our ancestors even called them "veins" of water'.[79] However, it is noteworthy that Seneca understood and explained the earth in terms of the parts and relationships of a human body, that is, he used a microcosm metaphor.

It has been argued that the weather cycle metaphor had a significant role in the discovery of the circulation of the blood, or in my terminology, Harvey used the conceptual framework provided by the weather cycle metaphor to interpret his complex anatomical observations. That is to say, Harvey might have made his discovery by drawing implications grounded in analogies of structure between the cardiovascular system and the weather cycle. The conceptual framework offered by the weather cycle metaphor can be presented as follows:

Sun	Heart
Earth	Body
Air	Arterial blood
Water	Venous blood
——	Arteries
——	Veins
——	Valves
Clouds	——

However, if we follow the implications of this scheme, it becomes apparent that this cannot be the case. The metaphor is suitable for the conceptualisation of the cardiovascular system only to a limited degree, because the analogies between the macrocosm of the weather cycle and the microcosm of the animal body breakdown at a superficial level. First, the scheme of correspondence between the weather cycle and the cardiovascular system is not complete. Counterparts for the blood vessels and the valves do not exist in the weather cycle. In turn, the cardiovascular system does not have a counterpart for clouds.

[79] Seneca, *Quaestiones naturales*, with an English translation by Thomas H. Corcoran (London: 1971) vol. III 15, 1–2.

Moreover, it is not enough to form a scheme of correspondence between the objects of the source and the objects of the target domain. In a good scientific metaphor, the most important relationships that hold within the source domain will also hold in the target domain. In particular, it is required that the most significant causal and spatial relations in the source domain can be carried across to apply in the target domain. With respect to spatial relations, the weather cycle metaphor is suitable for the conceptualisation of the circular movement of blood. That is to say, sun warms the wet earth and the moist air rises and cools. The cooling causes the moisture to condense and fall as rain. Similarly, the blood moves from the heart to the body by way of the arteries and returns to the heart by the veins.

Apart from this, the spatial relations from the weather cycle cannot otherwise be imported to apply to the cardiovascular system. Harvey's point is that the heat of the heart converts venous blood into arterial blood in the same way that the heat of the sun evaporates water into air. However, applying the weather cycle metaphor would suggest that the heart is not a part of the body, because the sun is not part of the earth. The evaporation of water into air happens outside the sun; hence, this would suggest that the conversion of blood takes place outside the heart. In this respect, the cloud would be a better counterpart for the heart because, in Aristotle's terminology, the coldness of the cloud condenses air into water.

With respect to causal relations, the weather cycle metaphor is a complete failure. The most important causal relation in the cardiovascular system is the relation between the heart and blood. The movement of blood is caused by the impulse of the heart. However, the weather cycle metaphor suggests that the heart does not cause the motion of the blood, because the sun does not cause the motion of air and water. According to Aristotle, each element has its natural place in the cosmos. Starting from the centre of the cosmos, the order of the four elements is as follows: earth, water, air, and fire. If an element is out of its natural position, it will attempt to move toward that position, requiring no external cause. Thus, air rises up and water falls down as rain.

The main point of Harvey's anatomical observations is that one of the actions of the heart is the very transmission of the blood and its propulsion to the extremities by the intermediary of the arteries.[80]

[80] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 51–52.

Although the circular movement of blood can be conceptualised with the help of the weather cycle metaphor, the metaphor provides no help in figuring out the relationship between the heart and blood. Thus, evidence strongly suggests that the weather cycle metaphor cannot be the origin of Harvey's discovery of the circulation of blood.

At the same time, Harvey's weather cycle metaphor is not merely a rhetorical device, as has been claimed occasionally.[81] First, it provides additional confirmation for the doctrine of the circulation of blood by showing that the movement of blood fits within the Aristotelian cosmology, that is, the movement of blood imitates a perfect circular motion.[82] Second, Harvey uses the metaphor as a cognitive instrument in another respect. With its help, Harvey explains the conversion of the venous blood into the arterial blood. According to his vitalistic explanation, the "heat" of the heart impregnates the blood again with spirit. The 'warmer, perfected, vaporous, full of spirit and so to speak, alimentative' blood circulates from the heart to the other parts of the body where it nourishes, warms, and activates the bodily parts. In the process, the blood becomes cold and coagulated as if it were enfeebled. After this, the blood returns to its beginning, the heart, 'as to the fountain or inmost shrine of the body to recover its perfection'.[83]

8. *Harvey's Use of Technological and Social Metaphors*

The role of mechanistic ideas, that is, technological metaphors in Harvey's scientific work, has been a matter of considerable debate. Harvey was not a mechanical philosopher, as can be seen, for example, in his later dispute with René Descartes. Descartes and Harvey had fundamentally opposed views on the legitimacy of vitalistic explanations

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[81] Whitteridge G., *William Harvey and the Circulation of the Blood* 126–128; French R., *William Harvey's Natural Philosophy* 106.

[82] Harvey published the *De motu cordis* 85 years after Copernicus had published the *De revolutionibus orbium coelestium* (1543). However, although in the Copenican model the sun was the center of the Solar system, the planets still executed uniform circular motion. Thus, Copernicus' heliocentric theory was compatible with the idea that circular motion is perfect when compared to all other kinds of motion.

[83] Harvey, *An Anatomical Disputation concerning the Movement of the Heart and the Blood in Living Creatures* 76.

in physiology.[84] However, there are mechanistic elements in both the *De motu cordis* and the *De motu locali*.

In *De motu locali*, Harvey refers to Aristotle's *De motu animalium* in which Aristotle compares the movements of animals with those of automatic puppets. Aristotle uses the automaton metaphor in an attempt to understand one of the defining features of organism, specifically, self-motion.[85] Harvey quotes twice the same passage from Aristotle's *De motu animalium*:

> The movements of animals may be compared with those of automatic puppets, which are set going on the occasion of a tiny movement; the levers are released, and strike the twisted strings against one another; or with a toy wagon. For the child mounts on it and moves it straight forward, and then again it is moved in a circle owing to its wheels being of unequal diameter, the smaller acting like a centre. Animals have parts of a similar kind, their organs, the sinewy tendons to wit and the bones; the bones are like the wooden levers in the automaton, and the iron; the tendons are like the strings, etc.[86]

The scheme of correspondence between the source domain of automatic puppet and the target domain of animal body is as follows:

Wooden levers	Bones
Strings	Tendons

Yet, while Aristotle compares the movement of animals to the movement of automatic puppets, he is not a "mechanical" philosopher. In mechanical philosophy, the organism is not only compared to a self-moving artefact, but the organism must also be understood to work in a comparable way. However, Aristotle thinks the natural and the artificial are different in kind. He explains the functioning of organisms by referring to the notion of the psyche.[87]

Like Aristotle, Harvey does not follow through on the automaton metaphor. Harvey does not base his investigations on the automaton metaphor or any other mechanism of muscular movement. Instead,

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[84] Gorham G., "Mind-Body Dualism and Harvey-Descartes Controversy" *Journal of the History of Ideas* 55 (1994) 211–234.

[85] Aristotle also uses the automaton metaphor in the *De Generatione Animalium* (734b9–18). In this case, the metaphor is employed to explain the process of reproduction.

[86] Harvey, *De motu locali animalium* 73 and 97–99; Aristotle *Movement of Animals*, in Barnes J. (ed.), *The Complete Works of Aristotle* (Princeton 1984) 701a1–a10.

[87] Guthrie, W.K.C., *A History of Greek Philosophy* vol. VI (Cambridge: 1981), 248–249.

he relies on metaphors derived from the social domain. The influence of Aristotle is also evident in this respect. Harvey refers to a passage in the *De motu animalium* in which Aristotle explains the functioning of animals by comparing the animal body to a well-governed city.[88] According to Aristotle, once order is established in a city, the individuals play their assigned part as it is ordered, and one thing follows another because of habit. 'So in animals the same thing happens because of nature, each part naturally doing its work as nature has composed it'.[89] Harvey's *De motu locali* ends with a long list of metaphors derived from the social domain:

> Is the brain the general? The nerves carry the commands, sergeant major. The spinal medulla the lieutenant-comet. The branches of the nerves which give the signal to the muscles, the captains. The muscles, the soldiers.
>
> Or is the brain the ruler of the senate for the purpose of deciding what useful things are present? The nerves, the magistrates. The branches of the nerves, the officials. The muscles, the citizens, the populace.
>
> Or again, is the brain the choir-master? The nerves, the time-keepers and prompters, dancers. The muscles, the actors, singers, dancers.
>
> Or is the brain the architect? The nerves, the overseers, surveyors. The branches of the nerves, the clerks of every work. The muscles, the workmen.
>
> Or is the brain the master? The spinal medulla, his mate. The nerves, boatswains. The muscles, sailors.[90]

Harvey's favourite is the choir-master metaphor. The scheme of correspondence is as follows:

Choirmaster	Brain
Time Keeper	Nerves
Muscles	Singers

It is noteworthy that this metaphor is based on the same two notions as the earlier macrocosm metaphor, namely, harmony and rhythm. Still, the metaphor is unsuccessful. It does not provide a satisfactory conceptual framework for the analysis of animal movement or introduce new topics for research. Harvey's remarks stay on a general level. According

[88] Harvey, *De motu locali* 147.
[89] Aristotle, *Movement of Animals* 703a30–35.
[90] Harvey, *De motu locali* 151.

to Harvey, the muscles are moved according to an order and rhythm at the direction of the soul.[91] Moreover, the sensitive and motive soul is in the brain.[92] Muscles are like 'separate living creatures', which have to be directed in harmony by the choirmaster of the brain.[93] For example, a movement of the hand is accomplished 'by the muscles working in the hand and by the spirit working in the muscles and by the heat working in the spirit and by the soul working in the body, by all these things acting together to this end'.[94]

In other words, animal movement is characterised by the harmonious coordination of muscles; movement is effected while 'the parts become greater and less by turns'.[95] Each muscle has its own rhythm of tension and relaxation in the same way as the heart has its systole and diastole. However, when Harvey attempts to apply his conceptual framework to the analysis of concrete animal movement, the results are not very interesting. For example, he says that chickens with their heads cut off still move, as do also men in delirium and drunkards, but they move with a disorderly action and not with the harmony and rhythm necessary for work.[96]

The role of technological metaphors in Harvey's discovery of the circulation of blood has also been a matter of debate. It is significant that the reception of Harvey's discovery occurred essentially under Cartesian influence.[97] Descartes was among the first to support Harvey's doctrine of the circulation of blood. However, since Descartes' mechanical philosophy was radically different from that of Harvey, Descartes modified Harvey's doctrine in accordance with his own, systematically eliminating Harvey's vitalism. As a result, part of Harvey's doctrines became firmly associated with some of Descartes'. This modification of Harvey's doctrine had a great impact on the reception of the doctrine of the circulation of blood.[98] According to Fuchs, Harvey's discovery 'was and is seen chiefly from a perspective that was determined to a great extent not by him, but by Descartes'.[99]

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[91] Harvey, *De motu locali* 147.
[92] Harvey, *De motu locali* 151.
[93] Harvey, *De motu locali* 111.
[94] Harvey, *De motu locali* 127.
[95] Harvey, *De motu locali* 153.
[96] Harvey, *De motu locali* 111.
[97] Fuchs T., *The Mechanization of the Heart* 2.
[98] Fuchs T., *The Mechanization of the Heart* 116; French R., *William Harvey's Natural Philosophy* 180.
[99] Fuchs T., *The Mechanization of the Heart* 2.

Descartes determined the tone of anatomical and physiological studies in the late 17th century far more than Harvey did. The doctrine of iatromechanism regarded the body as a Cartesian machine, conforming in its function to mechanical laws. The representatives of the iatromechanism tradition used mechanical and hydraulic models and mechanical forms of explanation to understand and explain the structure and function of human and animal bodies. Iatromechanist Marcello Malpighi (1628–1694) was a pioneer in the use of the then recently invented microscope. In 1661, he located capillaries, the link between arteries and veins that had eluded Harvey.

Later in the 17th century, mechanical philosophers often interpreted Harvey's theory in mechanical terms, summed up by the phrase "the heart is a pump". Yet, Harvey never compared the heart to a pump in the *De motu cordis*. The closest he comes is in comparing the heart indirectly to a syringe: 'The arteries pour out the blood driven by a propelling force in very great quantity and in spurts, as if it were ejected out of a syringe (*sypho*)'.[100]

In *De motu cordis* the only detailed use of technological metaphor can be found at the beginning of Chapter 5. Harvey compares the heart to a machine or a musket. However, it is a question of an attribute metaphor. In all three, the successive movements, because of their rapidity, seem to happen at once as in the wink of an eye. In the heart, the movements of the auricle and the ventricle follow each other so quickly that only one movement can be observed. The same applies to the musket, where touching of the trigger brings down the flint, lights a spark, which falls in the powder and explodes it, firing the ball, which reaches the mark.[101]

The comparison between the heart and a pump can be found only in later works. Harvey's *Praelectiones anatomiae universalis* is a collection of handwritten notes for the Lumleian lectures of 1616 and the following years. While discussing the anatomy and function of the heart, Harvey makes the following comparison: 'It is certain from the structure of the heart that the blood is perpetually carried across through the lungs into

[100] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 82.

[101] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 50–51.

the aorta as by two clacks of a water bellows to raise water'.[102] However, Gweneth Whitteridge has provided strong evidence in favor of the view that the short statement is a later addition to the manuscript. Although there is no way of knowing for sure, the handwriting of the passage suggests that it could well have been written as late as 1626 or 1627.[103] Thus, in all likelihood, it was added after the publication of the *De motu cordis*. In the *Second Anatomical Exercitation on the Circulation of the Blood to Riolan* (1649), Harvey makes the comparison between the heart and a pump while discussing the spurting of blood from a split artery. The latter can be compared to the jets of water squirted through the leaden pipes of a fire engine. In the same way as the spurting of blood is caused by the force and impulse of the heart, the jet of water is a result of a functioning of a fire engine pump.[104]

The lack of explicit comparison between the heart and a pump in the *De motu cordis* has been often interpreted as proof that the pump metaphor or any other technological metaphor 'did not play a central role in Harvey's discovery of the theory of circulation'.[105] Moreover, Charles Webster argues that Harvey's 'mechanical analogies were of illustrative use only'.[106] Walter Pagel states that the pump metaphor had 'no major significance for the discovery as such'.[107] Harvey's idea of the closed circulation of blood can pass as an eminently modern hydraulic scheme only when abstracted from 'a world of ideas that are quite different in scope and decidedly not modern'.[108] Andrew Gregory maintains that Harvey's use of the weather cycle metaphor is 'considerably more significant for him than the pump analogy'.[109]

One must distinguish, however, between two technological metaphors in Harvey's thought. It is true that the pump metaphor as such did not have a role in Harvey's discovery. Harvey does not compare the internal structure and functioning of the heart to the internal structure and functioning of a mechanical pump in the *De motu cordis*. But, Harvey's

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[102] Whitteridge G., *The Anatomical Lectures of William Harvey/Prelectiones Anatomie Universalis De Musculis* (Edinburgh-London: 1964) 273.

[103] Whitteridge G., *The Anatomical Lectures of William Harvey* xxix.

[104] Webster C., "Harvey's Conception of the Heart as a Pump" *Bulletin of the History of Medicine* 39 (1965) 510–511; Pagel W., *William Harvey's Biological Ideas* 213.

[105] Webster C., "Harvey's Conception" 517.

[106] Webster C., "Harvey's Conception" 515.

[107] Pagel W., *William Harvey's Biological Ideas* 213.

[108] Pagel W., *William Harvey's Biological Ideas* 81.

[109] Gregory A., "Harvey, Aristotle and the Weather Cycle" 167.

main object of study there is not the heart but the cardiovascular system as a whole. Although Harvey does not talk about the heart as a pump, he discusses the cardiovascular system as whole in mechanistic terms, seeing it as a "hydraulic mechanism".[110] This aspect of the *De motu cordis* has been acknowledged by some Harvey scholars. According to Webster, Harvey's conception of the cardiovascular system as a hydraulic system owes something to the work of the hydraulic engineers who were active at that time in devising different kinds of waterworks and drainage pumps.[111] According to Roger French, Harvey may not have seen the heart as a pump, but he talked about and experimented with blood vessels as pipes. Moreover, French maintains that Harvey's experiments on the heart and vessels would have worked on a machine, adding that Harvey's concern with valves is also part of this story.[112]

One of the main differences between Harvey and his predecessors was Harvey's mechanistic reinterpretation of the notion of "valve". First, what Harvey called a "valve" was for his predecessors a collection of structures. What they called "*valva*" are nowadays called the "flaps" of the valve. Harvey's "valve" was "*valva*" together with "*orificium*", indicating the orifice of the vessel where the flaps winged. Moreover, it was usual for the flaps not to completely close the orifice.[113] Second, pre-Harveian anatomists interpreted their anatomical observations in the framework of the Galenic theory. Harvey's teacher Fabricius rediscovered these structures in the venous veins in 1574 and called them "*ostiolum*" ("little doors"). The venous valves had been described by others before Fabricius, but he published the first extensive anatomical account in the *De venarum ostiolis* (1603). Although Fabricius noticed that the venous valves opened upward in the lower limbs, he still misunderstood their function. Fabricius remained an advocate of the Galenic theory that the direction of blood flow is always from the heart to the extremities. In his view, the valves were partially open "little doors" and their function was to delay the rushing of blood to the outer limbs.[114]

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[110] For the comparison between the water circulation in a plant and in a hydraulic mechanism, see the article by Epple in this volume.

[111] Webster C., "William Harvey and the Crisis of Medicine in Jacobean England", in J. Byleby (ed.), *William Harvey and his Age* (Baltimore-London: 1979) 21–22.

[112] French R., *William Harvey's Natural Philosophy* 350.

[113] French R., *William Harvey's Natural Philosophy* 352.

[114] Pagel W., *William Harvey's Biological Ideas* 20.

Harvey argued that the function of valves was to impose unidirectional flow of the blood. Later, when Robert Boyle met Harvey before Harvey's death and asked him about the origin of the discovery, Harvey answered by referring to his observations concerning the structure of venous valves. These valves were 'so placed that they gave free passage to the blood towards the heart, but opposed the passage of the venal blood the contrary way'. According to Harvey, 'so provident a cause as nature had not so placed so many valves without design; and no design seemed more probable, than that, since the blood could not well, because of the interposing valves, be sent by the veins to the Limbs, it should be sent through the arteries, and return through the veins, whose valves did not oppose its course that way'.[115]

In *De motu cordis*, Harvey says that 'a vein does not differ from an artery by the thickness of its coat, but they are differenced by their office and by their use'.[116] In this respect, Harvey disagreed with Galen. Galen emphasised the structural differences between the thin-walled veins and the heavier arteries. The heavier wall of the artery was supposed to keep the air and heat from escaping through the wall of the blood vessel before arriving at the organs.[117] Moreover, Harvey says that an artery (*arteria*) is a vessel carrying the blood away from the heart into the whole of the body. In turn, a vein (*vena*) is a vessel bringing the blood from the body into the heart.[118] In Chapter 13 of *De motu cordis* he refers to the structural difference between arteries and veins. According to Harvey, there are 'no valves in the arteries'.[119] Harvey was aware that there were valves not only in the veins of the limbs, but in the renal, mesenteric and jugular veins as well.[120] What the valves all have in common is that they all "look" towards the roots of the veins and everywhere towards the region of the heart.[121] According to Harvey,

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[115] Robert Boyle, *The Works of the Honourable Robert Boyle. In six Volumes. To which is prefixed the Life of the Author. A New Edition* vol. 5 (London: 1772) 427. *Eighteenth Century Collections Online*. Gale Group. http://galenet.galegroup.com/servlet/ECCO

[116] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 76.

[117] Siegel R., *Galen's System of Physiology and Medicine* (Basel: 1968) 89.

[118] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 77.

[119] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 101.

[120] French R., *William Harvey's Natural Philosophy* 108.

[121] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 101.

such is 'their constitution that they stop and resist all movement of the blood which is begun in the greater veins and ends in the lesser'.[122] Yet, Harvey continues, any movement which begins in the small veins and ends in the greater, they obey and provide a free and open way for it.[123] Thus, according to Harvey, the valves in the veins are like the valves in pipes that allow only the unidirectional flow of fluid.

Although Harvey did not explicitly compare the heart to a pump in *De motu cordis*, the heart functions like a pump as part of the hydraulic mechanism. According to Harvey, one of the actions of the heart is the very transmission of the blood and its propulsion to the extremities by way of the arteries.[124] Harvey says:

> First, the auricle contracts itself, and in that contraction throws the blood with which it abounds as the head of the veins and the storehouse and cistern of the blood, into the ventricle of the heart, which being filled, straightway the heart raises itself, tenses all its fibres, contracts the ventricles and makes a beat, by which beat it forthwith thrusts the blood sent in from the auricle into the arteries.[125]

Thus, the scheme of correspondence between the cardiovascular system and the hydraulic mechanism is as follows:

——	Body
Fluid	Arterial blood
Fluid	Venous blood
Pipes	Arteries
Pipes with valves	Veins
——	Heart

The scheme could be expanded by saying that the auricle of the heart is a cistern and the ventricle of the heart a syringe (as mentioned earlier). Although one cannot be sure, this evidence strongly suggests that the hydraulic mechanism metaphor was the structured conceptual framework that Harvey employed to interpret and explain

[122] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 103.
[123] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 103.
[124] Harvey, *An Anatomical Disputation concerning the Movement of the Heart and the Blood in Living Creatures* 51–52.
[125] Harvey, *An Anatomical Disputation concerning the Movement of the Heart and the Blood in Living Creatures* 50.

his anatomical observations. Unlike the weather cycle metaphor, the hydraulic mechanism metaphor is suitable for the conceptualisation of both the circular movement of blood and the role of the heart in the movement of blood.

Harvey's train of thought can be reconstructed as follows. The auricle of the heart is the cistern, which supplies the blood for the ventricle. In the same way as a pump propels the fluid into the pipes, the ventricle of the heart propels the blood into the arteries. After this, Harvey was faced with a difficult problem. The amount of blood that passes out of the heart is so large as to cause problems. The arteries would rupture from the overflow of blood. Harvey's solution was the reinterpretation of the notion of "valve". He argued that the valves in the veins are like the valves in the pipes of a hydraulic mechanism, that is, they allow only the unidirectional flow of blood. Moreover, he noticed that all the valves in the veins point to the heart. They were so placed that they gave free passage to the blood toward the heart, but opposed the passage of the blood to the outer limbs. In other words, the motion of blood in the arteries was from the heart to the extremities, and in the veins from the extremities to the heart. Thus, Harvey was able to conceptualize the circular movement of blood with the help of the hydraulic mechanism metaphor, making it the "cognitive instrument" behind the discovery of the circulation of the blood.

9. *Social vs. Technological Metaphors*

The success of the "hydraulic mechanism" metaphor in Harvey's *De motu cordis* throws some light on the failure of the *De motu locali.* In *De motu locali*, Harvey's use of social metaphors hindered his investigations of animal movement, because there are crucial differences between social and technological metaphors. First, the structure and function of a social relation or institution is often a bit vague. This can be shown by Harvey's choirmaster metaphor. A choir can be defined as a group of people assembled to sing together. A choir is often led by a choirmaster, but most choirs can also perform without a choirmaster. Moreover, a choir can sing with or without instrumental accompaniment. Compared with a social institution, the structure and function of an artefact is rigid. For example, for a hydraulic mechanism to function, it must have certain parts (e.g. pump, pipes, valves, fluid, etc.). A hydraulic mechanism without a pump is only a useless collection of mechanical parts.

Moreover, the parts must be arranged in a certain order, for example, the valves must open and close in the right direction. Thus, compared with a social metaphor, a technological metaphor usually provides a much more clearly defined conceptual framework for the analysis of unfamiliar or novel natural phenomena.

Second, and more importantly, artefacts, especially machines and automata, can be described in terms of mathematical relations among their moving and stationary parts. Once Harvey saw the cardiovascular system as a hydraulic mechanism, he could transfer these mathematical relations from the source domain of technology to the target domain of the cardiovascular system. Harvey's famous quantitative argument for the circulation of blood can be understood against this background. One can calculate the amount of fluid that a pump propels into a system of pipes in a given time by multiplying the volume of the pump cylinder with the number of times that the piston goes through a complete cycle. In Chapter 9, Harvey makes a similar calculation with regard to the cardiovascular system. First, he estimates how much blood the left ventricle may contain in its dilation. Then, he investigates how much smaller a capacity the ventricle has in its contraction, and how much blood is propelled into the arteries by each beat of the heart. Finally, he multiplies the amount of blood sent forth at every beat of the heart by the number of heartbeats in a given time. His results show that the volume of blood is more than what can possibly be supplied by the food we eat or contained in the veins at one time.[126] That is to say, the only possibility is that the blood circulates. In this way Harvey's use of the hydraulic mechanism metaphor is intimately linked with his quantitative argument.

The choir metaphor does not offer similar advantages. Although harmony and rhythm have a definite mathematical meaning in music, they usually refer to a subjective feeling in other things. For example, in design, harmony describes a "pleasing" arrangement characterised by the even distribution of elements. In this respect, it is interesting to compare Harvey and Johannes Kepler (1572–1630). Kepler, Harvey's contemporary, used the "cosmic harmony" metaphor in his astronomical investigations. The Pythagoreans were the first to discover that the pitch of a musical note is determined by the length of the string which

[126] Harvey, *An Anatomical Disputation Concerning the Movement of the Heart and the Blood in Living Creatures* 79–80.

produces it. In other words, they discovered that the intervals of the musical scale correspond to simple numerical ratios. Later, Pythagorean thinkers developed the doctrine of a universe ordered by the same numerical proportions that govern musical harmonies.[127] Kepler's *Harmonices mundi* (1619) was based on Pythagorean ideas. Kepler found harmonic proportions expressible in musical terms in the relationships between the angular velocities of all the planets. In fact, it can be argued that Kepler discovered the laws of planetary motion while attempting to find the "the music of the spheres".[128] Kepler's success was based on his ability to transfer the mathematical relations of the musical scale from the source domain of music to the target domain of planetary movement. However, the harmonious action of the animal body cannot be described with the help of numerical proportions that govern musical harmonies. Harvey's notion of harmony was based on a subjective feeling, and, thus, it did not meet the criteria for an exact or "scientific" description of the phenomenon in question.

[127] Haar J., "Pythagorean Harmony of the Universe" 38.

[128] Godwin J., *Harmonies of Heaven and Earth: The Spiritual Dimensions* (London: 1987) 144–145.

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LEGITIMATING THE MACHINE: THE EPISTEMOLOGICAL FOUNDATION OF TECHNOLOGICAL METAPHOR IN THE NATURAL PHILOSOPHY OF RENÉ DESCARTES

Andrés Vaccari

Introduction

One of the salient features of early modern science is a conspicuous proliferation of mechanical imagery applied to all conceivable natural phenomena. These tropes are part of a complex historical shift, marking the emergence of a distinctly modern scientific attitude modelled in close partnership with craftsmanship and engineering. Metaphors of automata, artefacts and technical activity performed a varied range of explanatory functions and are found in a number of analogical constructions: the world as machine, God as artisan, nature as handicraft, the world as rational design, the philosopher as engineer, etc. We can use the term 'machine metaphor' as a convenient way of referring to this multifarious constellation of images, conceptual approaches, explanatory devices, and rhetorical and pictorial strategies. All these discursive artefacts are interconnected in complex ways, finding their common source in the technocultural milieu of the early modern period; that is, in real artefacts. It is not my intention, here, to offer a comprehensive overview of this phenomenon, but to consider one momentous historical case: that of René Descartes (1596–1650).

Among his many considerable achievements, Descartes was the first to extensively and systematically introduce the machine metaphor into the biological sciences, exploring the poetic and conceptual possibilities of a mechanical theory of life. But my main focus of interest will be the way Descartes set out to legitimate the machine metaphor as an exemplary instrument of the new science, at a time when the role of analogy and other rhetorical tropes in natural philosophy was being intensely questioned. In this respect, Francis Bacon's attack on the excesses and vagaries of rhetoric and language (the 'Idols of the Market', in *The Great Instauration* [1620]) are well known.

A central aspect of the scientific revolution was a search for new rhetorical strategies; techniques of representation; and ways of presenting,

circulating and advertising natural-philosophical knowledge. Descartes' case is unique because of the imaginative way in which he sought to ground heuristics on firm metaphysical and epistemological foundations. Descartes privileged technological images (machines, everyday artefacts, and the activity of engineers, artists and artisans) above all others, showing a keen fascination with the technology of his day; in particular, automata, the microscope, perspective representation, optical artefacts, mechanical illusions, and the textual and pictorial techniques of machine treatises and post-Vesalian works on anatomy.

Descartes' natural philosophy is an exemplary case of the alliance of systematic reason and technological practice that characterizes the techno-scientific turn of the seventeenth century. Descartes' language coalesced many heterogeneous and disparate dimensions of technological experience; these 'ways of being' of technology cut across various technical, socio-cultural and discursive dimensions, where technology variously appeared as an object of rational knowledge; a site of spectacle and wonder; a symbol of certain kinds of knowledge and an emblem of the new science; as a practical problem for engineers, in a range of contexts; in the shape of new scientific instruments; as the abstract object of mechanics; and as the subject of illustrated technological treatises.

As a self-styled solitary traveller and observer, Descartes had access to a range of culturally and socially fragmented experiences; their creative incorporation actively and profoundly shaped the direction of his thought. The intellectual milieu of the period, however, was also pushing in this direction. We can briefly outline five *main* areas in which technological metaphors played an important role in the scientific revolution:

1 – As *structural* metaphors, where the arrangement of parts of a certain artefact is regarded as analogous to that of a natural object. Perhaps the most significant example is the analogy between the eye and the *camera obscura*.

In the notes to his edition of *Treatise on Man*, Thomas Hall argues that the gradual rise of modern optics was closely associated with certain technological developments.[1] First, the lens of the eye (the crystalline

[1] René Descartes, *Treatise on Man*, transl. and annotated by Thomas Steele Hall, Prometheus Books (New York: 2003) n. 90, 51–52.

humour at its centre) had to be conceived as a refractor rather than a sensor. Once lenses began to be widely manufactured and better understood, the analogy was suggested and buttressed by experiments showing that organic and technological lenses both behaved in the same manner. Simultaneously, the retina (from Latin *tunica reti similis*, 'membrane like a net'), began to be conceived as a *receiver* of the two-dimensional image, after refraction and conduction by the rest of the eye. The analogy developed in close connection to the *camera obscura*,[2] as the two elements of this device (hole and screen) became functionally (and for Descartes ontologically) equivalent with the lens and retina, respectively.

2 – Artefacts embodied a *mode of action*. The focus in this case was not so much on the physical structure of the machine but on the way in which it works. Aristotle had used images of mechanical puppets and other machines to illustrate the *efficient* mode of causation.[3] Here, the key piece of technology is the mechanical clock. The late medieval period was marked by the effort to reconcile and adapt the thought of pre-Christian thinkers like Plato and Aristotle to the framework of Christianity. During this period, science 'was transferred [...] from the ontological context of God as the first cause existing knowably within nature to that of God as the totally

[2] The first mention of such a device is by the Arab philosopher Alhazen (Abu Ali al-Hasan ibn al-Haitham, approx. 965–1041), in his *Kitab al-manazir* (*The Book of Optics*; Latin: *De aspectibus*). His experiments served to establish the fact that rays of light could pass through a very small hole without interfering with each other (Park D., *The Fire within the Eye: A Historical Essay on the Nature and Meaning of Light*, Princeton University Press [New Jersey: 1997], 83–4). Giambattista de la Porta popularised it in *Magia naturalis* (1589) and *De refractione* (1593). In his own *Optics*, Descartes repeats the *camera obscura* metaphor: '[...] the objects we look at do imprint very perfect images on the back of our eyes. Some people have very ingeniously explained this already, by comparison with the images that appear in a chamber, when having it completely closed except for a single hole, and having put in front of this hole a glass in the form of a lens, we stretch behind, at a specific distance, a white cloth on which the light that comes from the objects outside forms these images. For they say that this chamber represents the eye; this hole, the pupil; this lens, the crystalline humour, or rather, all those parts of the eye which cause some refraction; and this cloth, the interior membrane, which is composed of the extremities of the optic nerve' (René Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, transl. by Olscamp P.J., The Bobbs-Merrill Company, Inc. [New York-Kansas City: 1965], 91). Henceforth, all references to *Optics* are from Olscamp's translation, and marked 'O'.

[3] E.g.: *On the Motion of Animals*, 701b, 702a 20–703; *On the Generation of Animals*, 734b–735a 4.

> separate omnipotent and inscrutable creator of nature […]'[4] With the assimilation of the clock image, the relationship of God-as-first-mover and the world was conceptualized in terms of machines that could move by themselves after an initial transfer of force. The rational, preordained design of the machine then ensured the continuation of harmonious motion. Thus, Marsilio Ficino (in his *Theologia Platonica* of 1576) describes an automaton Regiomontanus demonstrated in Florence in 1475, in which a single counterweight powered an arrangement of moving animals, singing birds and sounding trumpets: 'Thus God by his existence alone, which is the same thing as his intellect and his will, and which is the simplest of all centres from which […] everything else leads like lines, with the easiest nod agitates whatever depends upon him.'[5]

In astronomy and cosmology, mechanical imagery came to represent the cosmos as a harmonious, skilful construction subject to determinable regularities. But moral, political and scientific meanings are impossible to disentangle, and the machine resonated with a significance previously reserved for natural and religious symbols. The political realm was a microcosm of the heavens, and the clock acted as an image of both social and cosmic order. Otto Mayr sums up the kinds of contexts the clock appeared in: '[…] the clock was called upon to illustrate the attributes of God; the harmony of the universe; the joys of paradise; temperance, the highest of the seven virtues; the truth of the new science; and the effectiveness of absolute monarchy.'[6]

The machine metaphor married these two conceptual aspects: efficient causation and intelligent design. Johannes Kepler was arguably the first to transform 'one of the stock metaphors of astronomy into a functioning analogy in mechanics.'[7] In 1605, while searching for a true astronomical hypothesis (as opposed to merely saving the appearances), Kepler writes that his aim

[4] Crombie A.C., *Styles of Scientific Thinking in the European Tradition*, 3 vols (London: 1994) vol. 2, 58.

[5] Crombie A.C., *Styles of Scientific Thinking* 468.

[6] Mayr O., *Automatic Machinery in Early Modern Europe* (Baltimore & London: 1986), 125.

[7] Kemp M., "Vision and Visualisation in the Illustration of Anatomy and Astronomy from Leonardo to Galileo", in Freeland G. – Corones A. (eds.), *1543 and All That: Image and Word, Change and Continuity in the Proto-Scientific Revolution* (Dordrecht-Boston: 2000) 43.

> is to show that the celestial machine (*caelestis machina*) is to be likened not to a divine living thing but rather to a clockwork (*horologium*) […] in so far as nearly all the manifold movements are carried out by means of a single quite simple magnetic corporeal force (*vis magnetica corporalis*), just as in a clockwork all the motions come from a single weight. Moreover I show that this physical cause (*ratio*) can be determined by numbers and geometry.[8]

Descartes' mechanistic physiology presents another stage in the transformation of the metaphor, as he banishes a fundamental Aristotelian principle: there are no 'movers' and 'moved' in nature; and consequently, no prime movers. Every particle is in motion, containing in itself the power to move others. As a consequence, the Cartesian automaton differs from the Aristotelian. For Descartes, as Des Chene writes, the machine is a self-mover mainly 'because some of its movements are comprised in self-perpetuating cycles: the periodic contraction and expansion of the heart, the depletion and replenishment of the blood, hunger and satiety, desiring food, seeking and obtaining it.'[9] Rather than a scheme of active and passive bodies, for Descartes *all* bits of the machine are active in a sense – they are 'moved movers'. Circular and circulatory motion is the underlying principle of Cartesian machines (cosmological, biological and in between), since motion must *produce its own cause*.

3 – The metaphor of God as *artifex*, as craftsman or technologist, also undergoes a transformation during the renaissance and subsequent periods. This metaphor encompasses a range of distinct constructions. For instance, as Daston and Park argue, the 'nature as art' metaphor conceived of the world as a pliable, somewhat passive object fashioned by the hands of God; whereas the 'nature as artisan' metaphor regarded nature as engaged in active deliberation and possessing a certain degree of autonomy.[10] We must also include, here, various conceptions of God as designer, architect, geometer, and so on. These metaphors were instrumental in determining the nature and reach of natural-philosophical knowledge.

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[8] Crombie A.C., *Styles of Scientific Thinking* 542.

[9] Des Chene D., *Spirits and Clocks: Machine and Organism in Descartes* (Ithaca-London: 2001) 25.

[10] Daston L. – Park K., *Wonders and the Order of Nature 1150–1750* (New York: 2001) 296–7.

4 – The activity of the natural philosopher became closer to that of the craftsman. Medieval thought grounded the distinction between scholar and craftsperson in certain theological schemes that drew categorical differences between manual labour and the contemplative life, mind and matter, and the heavenly and the sublunary. By the end of the seventeenth century, these key metaphysical distinctions had been worn away, leading to 'a drastic weakening of the art/nature distinction.'[11] The story is quite convoluted, beginning perhaps with the emergence of an experimentalist tradition in the late Middle Ages and the rise of the humanist 'rational artist' during the renaissance. The ancient sources include Plato's *Timaeus*, Aristotelian conceptions of art imitating nature and nature imitating art, and Vitruvius' remarks on the education of the architect at the beginning of his *De architectura*. The main point of contact, here, is the conception that in nature, as in art, rational deliberation preceded material conception. By the late sixteenth century, the world of the craftsperson and engineer suggested a model of knowledge in which nature became like a manufactured object, a thing to be coaxed and scrutinized.[12]

5 – Finally, the mathematical approach to the physical world that lies at the core of modern science was shaped in part through the elevation of mechanics to a new, exalted status. Mechanics, like optics, was a *scientia media*, halfway between mathematics and physics. The early moderns began to regard the science of machines as an exemplary case of how mathematics can be applied to the understanding and modelling of physical phenomena. In his notion of mechanics Descartes conflated two distinct sources: the traditional sense of a branch of mathematics; and technological practice and engineering: the construction and study of machines.

All the dimensions outlined above provide the context for Descartes' own vision. What set him apart was his effort to provide a clear rationale for the development and application of tools of representation such as analogies, thought experiments, pictures, diagrams, etc. As we shall see,

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[11] Dear P., *Discipline and Experience: The Mathematical Way in the Scientific* Revolution (Chicago-London: 1995) 151.

[12] See also Rossi P., *Philosophy, Technology and the Arts in the Early Modern Era* (New York: 1970).

although a diagram and a metaphor are quite different things, they are connected by the same context.

This project of legitimation can be most explicitly reconstructed from Descartes' discussions on the nature of comparisons, the mechanisms of ideation and perception, and the nature and purposes of scientific knowledge. The Cartesian theory of analogy concerns mainly the relation between objects and cognitive impressions, and how our management and validation of these impressions can lead to valid knowledge. It has a firm footing in Descartes' metaphysics of matter and permeates numerous dimensions of Descartes' thought, bringing together physics, the physiology of perception, the hierarchy of the sciences, and his views on human knowledge. Descartes also demonstrates the explanatory promise of machine metaphors by *applying* them, showing mechanical modelling at work, and creatively transforming the technological milieu of his age into workable models.

The machine is, however, more than just a metaphor or model, and comes to inform Cartesian explanatory strategies at an intimate level, in the form of conceptual, rhetorical and pictorial structures derived from machine treatises, automata theatres, the microscopic imaginary, and other technocultural sources. I will call this level 'meta-analogical'. The machine is, for Descartes, a metaphysical thesis, coming to express a philosophical commitment about the ultimate nature of physical (extended) substance. This ontology or ruling metaphor is what ultimately threads together these various mutations of technology. The machine articulates a metaphysics of matter centred on the interaction of indivisible elements acting according to laws of motion, force and geometric figure. The corpuscularian conception of nature stood in stark contrast to previous models based on hidden correspondences and the belief in qualities or faculties inherent in substances. Descartes sought to restrict to a minimum the principles involved in the operations of matter, offering a model of local mechanical action in which corpuscles move as a result of direct contact or impact – this also being the main attraction of a plenarist metaphysics. Thus, in matters concerning the whole of the physical universe, Descartes, the famous dualist, is a radical monist. There is a principle of *immanence* to Cartesian mechanistics which postulates a single, continuous plane of material action, crossing the boundaries between natural, living and artificial. The machine, then, is a high-level concept connecting areas of knowledge as diverse as anatomy and cosmology, while also informing the application of particular artefacts in specific contexts. Finally, the

machine metaphor comes to inform the technological orientation of Cartesian science, the aim of which is to produce representations of the world that can facilitate manipulation and intervention.

In order to follow this transversal thread across Descartes' natural philosophy, I will leave aside some important aspects of the machine question. I will not discuss, for example, the incorporation of hydrostatics and hydrodynamics into Cartesian physics.[13] I also touch only lightly on the role of the automaton metaphor in physiology and the theory of life and the complications it encountered. The machine was also implicated in various theological and moral questions, such as free will, moral responsibility, and the nature of human judgment. The moral and religious aspects of bodily automatism were the most significant to Descartes' contemporary and future audiences, eclipsing to a large extent its scientific aspects. Lastly, I will not discuss the history of technology, and the sources of these images and concepts (a fascinating area in its own right) will be addressed only cursorily. I will assume some familiarity with baroque technology, crafts and techniques. My main focus is how the machine metaphor is used to figure the cognitive activity of natural philosophy, how it shapes its nature and aims.

I begin with Descartes' philosophy of analogy in scientific method, then examine some concrete applications of analogies in physics. These analogies are then contextualized in terms of Descartes' wider philosophy of knowledge, where technological images come to represent some aspects of scientific activity. I argue that these images also shape the orientation of natural knowledge, which Descartes regards as consisting of provisory hypotheses that must have efficacy in the world. Then, I turn to more properly epistemological aspects, regarding Descartes' theory of perception and how analogical thinking fits into this. In this context, I highlight the role of optical deceptions in providing a model of how we perceive the world. Descartes, however, believed in the inherent rationality of the universe: our knowledge is not merely illusory and arbitrary, but rests on a proportionality between ideas, figures in the brain and the things of the world.

In the last two sections, I turn to *Treatise on Man*, Descartes' most extraordinary deployment of mechanical metaphor. I argue that this

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[13] This has been exhaustively explored by Stephen Gaukroger. See, in particular, "The Foundational Role of Hydrostatics and Statics in Descartes' Natural Philosophy", in Gaukroger S. – Schuster J. – Sutton J. (eds.), *Descartes' Natural Philosophy* (London-New York: 2000).

can be considered the last stage in the mechanization of nature: the point at which machines themselves are subsumed into Descartes' project of a mathematical physics, thus prefiguring modern notions of technology. Lastly, I focus on some aspects of the machine as a system of representation: how certain technocultural sources inform Descartes' techniques of visualization and pictorial representation.

One very last caveat concerns the use of terms such as 'image', 'metaphor', 'analogy', 'technology' and 'science'. For the purpose of this argument, and unless otherwise stated, I will use the terms 'metaphor', 'analogy', and 'image' as more or less synonymous. Part of my argument, here, is that Descartes' use of machine images exceeds easy classification and that it is important to examine the phenomenon as a whole.[14]

'Science', 'technology' and their related terms are gross anachronisms when speaking of the seventeenth century. My main justification for using them is to draw certain historical continuities, to trace genealogies of concepts and practices that, in retrospect, bear on science and technology as we know them. Science refers, in general, to the study of nature; while technology refers to the activities of artisans and engineers, to the universe of machines, techniques and surrounding cultural forms, and to a particular world-view that seeks (to use Descartes' words) the 'mastery of nature'. I apply the term 'technological' also to a certain attitude that regards explanations and forms of representation as having instrumental value, and subordinate 'true' knowledge to the aims

[14] Some examples might clarify the issue. In the *Treatise on Light*, the analogy of two boats travelling along two intersecting rivers illustrates how comets pass from one circulatory current to another, while planets tend to gravitate towards the centre [AT XI 57–60; René Descartes, *The World and Other Writings*, ed. Gaukroger S. (Cambridge-New York: 1998) 38–9. Henceforth, all references to *The World* and *Man* are from Gaukroger's edition, and their page numbers are indicated with a 'G' after the AT reference.] Where this is clearly an analogy, another example a bit further on is a model: to explain how individual corpuscles exert force on each other, and how this affects the collective behaviour of matter in motion, Descartes employs the image of an arrangement of rows of balls, spaced at different intervals (AT XI 91–6, G 58–61). The line between analogy and model is thin at times, but the latter implies a more artificial set-up; in this case, a thought experiment that (it is assumed) can be carried out in practice. An analogy is a 'highly selective similarity', or 'a way of aligning and focusing on relational commonalities independently of the objects in which those relations are embedded' (Gentner D. – Jeziorski M., "The Shift from Metaphor to Analogy in Western Science", in Ortony A. (ed.), *Metaphor and Thought*, [Cambridge: 1993], 448–9). The 'body as machine' image in the *Treatise on Man*, as we shall see, can be more accurately characterized as a metaphor, a comparison that is broader in scope, more 'vague'.

of intervention. In the seventeenth century, this attitude is articulated through images of natural objects as technical products or processes.

1. *Figures and Clocks: Artefacts and the Cartesian Theory of Metaphor*

Analogies play a central explanatory role in Descartes' natural philosophy, and he seized them 'as his principal tool of investigation',[15] seeking to employ them rigorously, as heuristic tools that would yield certain and useful knowledge. In Rule Fourteen of the *Regulae*, Descartes discusses the method of comparing two things to one another, arguing that human knowledge proceeds by abstracting common ideas from various subjects of observation:

> Indeed, it is by means of one and the same idea that we recognize in different subjects each of these familiar entities, such as extension, shape, motion and the like [...]. This common idea is carried over from one subject to the other solely by means of a simple comparison, which enables us to state that the thing we are seeking is in this or that respect similar to, or identical with, or equal to, some given thing. Accordingly, in all reasoning it is only by means of comparison that we attain an exact knowledge of the truth.[16]

Descartes, offers a working definition of analogy, announcing its centrality in his project. The comparison of two things yields a third term: universal abstractions that are (as we shall see) at once clear rational principles and the simplest features of matter, such as extension, shape and motion.

As Galison observes, most of the metaphors found in the philosopher's writings are of everyday objects and phenomena, such as 'slings, canes, tennis balls, brambles, springs, clocks, robots, pulleys, pipes, organs, ships.'[17] As this list suggests, Descartes' favourite source domain consists of everyday artefacts, tools and machines. Despite Descartes' sceptical stance towards the evidence of the senses, in his investigative method

[15] Galison P., "Descartes's comparisons: From the invisible to the visible", *ISIS*, 75 (1984), 311.

[16] AT X 439, CSM I 57. 'AT' refers to Adam and Tannery's edition of Descartes' works. 'CSM' refers to the standard English translation of selected works: René Descartes, *The Philosophical Writings of Descartes*, 3 vols., Cottingham J. – Stoothoff R. – Murdoch D. (eds.), (Cambridge-New York: 1985).

[17] Galison P., "Descartes's comparions" 311.

these everyday objects play a friendlier role as maidens of knowledge. Descartes says in the *Discourse* that, regarding observations,

> [...] the further we advance in our knowledge, the more necessary they become. At the beginning, rather than seeking those which are more unusual and highly contrived, it is better to resort only to those which, presenting themselves spontaneously to our senses, cannot be unknown to us if we reflect even a little.[18]

However, as Brian Baigrie points out, these mundane images can help us procure true knowledge *only if* 'some of the properties of bodies of our experience are genuinely representational; that is, that we obtain genuine knowledge of bodies of mundane experience via sensation.'[19] This genuine knowledge consists in the simplest features of material nature: size, motion and figure. These principles remain the same regardless of how large or tiny the bodies are. In a letter to Morin, Descartes states:

> [...] in the analogies which I employ, I compare movements only with other movements, or shapes with other shapes; that is, I compare things that are too small to be perceived by the senses with other things that can be so perceived, the latter differing from the former simply as a large circle differs from a small one. I maintain, therefore, that analogies of this sort are the most appropriate means available to the human mind for laying bare the truth in problems of physics.[20]

Analogy has an ontological basis, as the comparison of two things that are of the *same nature*. The only differences between macroscopic and subvisible things are *size* and *complexity of arrangement*: strictly quantitative criteria. Thus, technological analogies could be considered an exemplary case of figuring the microscopic by way of the macroscopic, serving as a heuristic tool to picture structure, force, and other features of matter in motion. A principle of geometric proportion ensures the equivalence and transferability of these features. In the Sixth Meditation, Descartes says that corporeal things

> [...] may not all exist in a way that exactly corresponds with my sensory grasp of them, for in many cases the grasp of the senses is very obscure

[18] AT VI 63, CSM I 143.

[19] Baigrie B.S., "Descartes' Scientific Illustrations and 'la grand mécanique de la nature'", in Baigrie B.S. (ed.), *Picturing Knowledge: Historical and Philosophical Problems Concerning the Use of Art in Science* (Toronto-Buffalo-London: 1993) 113.

[20] AT II 367–8, CSM III 122.

> and confused. But at least they possess all the properties which I clearly and distinctly understand, that is, all those which, viewed in general terms, are comprised within the subject-matter of pure mathematics.[21]

Geometrical reasoning as figuration (as distinct from geometrical reasoning as axiomatic-deductive thinking) pertains to *bodies*: 'corporeal nature [...] is the subject-matter of pure mathematics [...].'[22] These simple natures offer an epistemic link between the 'distinct understanding' *qua* language of ideas (innate in the mind) and the corporeal figures abstracted from everyday experience. As Galison explains, for Descartes the role of the imagination is to 'depict a macroscopic image to the rational soul',[23] while the role of its products (comparisons and analogies) is to 'bridge the gap from the invisible corpuscles of natural phenomena to visible figures in the brain.'[24]

The series of analogies offered in the First Discourse of *Optics* is an exemplary case in point. Descartes tells us that he does not need to explain the 'true nature' of light, only to 'explain how its rays enter into the eye, and how they can be deflected by the different bodies that they encounter [...].'[25] Descartes says he will 'make use of two or three comparisons' to help the reader conceive of light and all 'its properties that experience acquaints us with', and 'to deduce afterwards all the others which cannot be so easily observed.'[26] He compares this method to that of astronomers, who use false or uncertain assumptions to draw 'many very true and well-assured conclusions.'[27]

The first comparison is that of walking at night with a stick, like blind people do to find their way around. This illustrates the first property of light: instantaneous transmission. A blind person can perceive differences between things solely by the medium of the stick; the same way we perceive colours by the diverse movements of matter. Descartes, here, insists on the lack of resemblance between cause and sensation, a topic that we shall encounter again soon.

The second comparison is that of a vat full of half-pressed grapes at vintage time.[28] There are two holes in the bottom of the vat. Descartes

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[21] AT VII 80, CSM II 55.
[22] *Meditations*, AT VII 74, CSM II 51.
[23] Galison P., "Descartes's comparions" 324.
[24] Galison P., "Descartes's comparions" 311.
[25] Descartes, *Optics* 66.
[26] Descartes, *Optics* 66.
[27] Descartes, *Optics* 67.
[28] Descartes, *Optics* 69.

argues that all the points on the surface will tend to go down simultaneously in a straight line towards these two holes. These 'tendencies to motion' (a key concept of Cartesian physics: the distinction between movement and the inclination to move) do not impede each other, but form lines of force that are transmitted across subtle fluids and hard bodies. The mixture of grapes acts as a microcosmic metaphor to illustrate how rays of light proceed from the sun, agitating the subtle material in interstellar space and forming rectilinear tendencies to motion that reach our eyes without impeding each other.

The third analogy is with tennis balls.[29] This is intended to explain deflection and refraction, since tendency to motion behaves in the same way as motion.[30] If we can imagine each particle as a ball bouncing off a surface, then different surfaces (smooth, concave, rough, etc.) will deflect each of these balls in a different angle. Similarly, if we can imagine a ball entering a liquid body, we can get a mental picture of how rays of light lose some of their motion and direction of motion upon entering a liquid medium.

The main point, is that each of these analogies illustrates one property of rays of light, and Descartes takes each of these both positively and negatively; i.e., he is quick to point out the limits of the image, and to draw attention to the mechanism of analogy itself. Each analogy is a provisory hypothesis and illustrates something that the previous one lacks. The blind person's stick illustrates instantaneity of movement; the vat of grapes, tendencies to motion; and the tennis balls, refraction and deflection. In each of these cases, the analogue is of the same nature as the primary subject; in fact, each analogy can be understood as a thought experiment, an imaginary experimental set-up. The ordinariness of the analogue buttresses their evidential strength. Secondly, the analogue is a macroscopic image of a microscopic phenomenon.

Thus, these analogies are instances of a single analogical strategy, cutting across Descartes' technocultural universe: the prosthetic enhancement of perception, the manufacture of wine, and an outdoor game. The machine metaphor is a transversal phenomenon: an abstract machine, a meta-physics, a meta-analogy that gathers and cements Cartesian physics. Each analogy will be a particular expression of the

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[29] Descartes, *Optics* 70–4.

[30] Descartes, *Optics* 70.

machine metaphysics. The vat of grapes indicates most clearly one of the sources of this abstract machine, in mechanics (hydrostatics). But it stretches far and wide, providing also the scaffolding for epistemology itself, as we shall see next.

2. *Knowing as Making: The Limits and Nature of Scientific Knowledge*

Technological analogies also serve another purpose: to figure the very activity of understanding. In a passage from *Principiae*, Descartes addresses the following objection: how can the philosopher assign determinate shapes, sizes, and motions to invisible particles as if he had seen them? Descartes begins his response by alluding to his first principles. He says he considered clear and distinct ideas of things and could find only shapes, sizes and motions, and the rules whereby these three things can be modified by each other (that is, the principles of geometry and mechanics). He continues:

> In this matter I was greatly helped by considering artefacts. For I do not recognize any difference between artefacts and natural bodies except that the operations of artefacts are for the most part performed by mechanisms which are large enough to be easily perceivable by the senses – as indeed must be the case if they are capable of being manufactured by human beings. The effects produced in nature, by contrast, almost always depend on structures which are so minute that they completely elude our senses. Moreover, mechanics is a division or special case of physics, and all the explanations belonging to the former also belong to the latter; so it is no less natural for a clock constructed with this or that set of wheels to tell the time than it is for a tree which grew from this or that seed to produce the appropriate fruit. Men who are experienced in dealing with machinery can take a particular machine whose function they know and, by looking at some of its parts, easily form a conjecture about the design of the other parts, which they cannot see. In the same way I have attempted to consider the observable effects and parts of natural bodies and track down the imperceptible causes and particles which produce them.[31]

This passage neatly articulates all the major areas in which technological analogy comes to play a part in Descartes' project. Firstly, we begin with an *ontological* assertion: the equivalence of natural bodies (both animate and inanimate) and artificial things. Secondly, the ontological

[31] AT VIIIA 326, CSM I 288–9.

leads to a *disciplinary* aspect, a rearrangement of the sciences: physics, concerned with natural bodies, is collapsed into mechanics, the science of machines. Although the latter is subsumed under the former, these two branches of knowledge deal with the same type of object; they are ruled by the same physical principles and are not metaphysically (in their 'nature') distinct. This epistemological attitude is closely modelled on the activity of the technologist ('men who are experienced in dealing with machinery'), which becomes the key to elucidating the unseen structures and mechanisms beyond available observation.

This attitude also extends to the nature and aspirations of knowledge. In the preface to the 1647 French edition of the *Principia*, Descartes proposes a reorganization of philosophy:

> Thus the whole of philosophy is like a tree. The roots are metaphysics, the trunk is physics, and the branches emerging from the trunk are all the other sciences, which may be reduced to three principal ones, namely medicine, mechanics and morals.[32]

In this schema mechanics encompasses the whole of the physical world; that is, the entirety of physics and biology. The three branches are the fruits of applying physics to the problems of human life: the betterment of our physical condition (medicine), the making of machines and rational improvement of techniques (mechanics), and the application of moral standards of conduct to everyday life (ethics). In Descartes' system (as *The Passions of the Soul* makes clear) both medicine and ethics depend heavily on the notion of the body-machine, as they depart from a mechanical understanding of bodily nature. Medicine and ethics have the same aims as mechanics: technological control with the aim of human utility. Descartes writes:

> This will indeed be sufficient for application in ordinary life, since medicine and mechanics, and all the other arts which can be fully developed with the help of physics, are directed simply towards applying certain observable bodies to each other in such a way that certain observable effects are produced as a result of natural causes. And by imagining what the various causes are, and considering their results, we shall achieve our aim irrespective of whether these imagined causes are true or false, since the result is taken to be no different, as far as the observable effects are concerned.[33]

[32] AT IXB 14, CSM I 186.
[33] AT IXB 322, CSM I 289.

Manipulation and intervention are, for Descartes, the ultimate goals of scientific knowledge. Mechanical imagery, in this context, is a 'natural' expression of the technological orientation of Descartes' thought. As Peter Schouls explains, the 'abstract thinking required for pure science is, for Descartes, never to be an end in itself', having an 'instrumental value only, [in] that it serves to lay the foundations for mastery.'[34] Thus, we must move 'from abstract thought to useful, practical knowledge as soon as this is legitimate, that is, as soon as abstract thought is sufficiently advanced to serve as proper foundation.'[35]

There is a tension, here, between the heuristic and the metaphysical, between metaphor and literality: technological images are, on the one hand, a provisory explanatory tool; yet, on the other, they are constitutive and foundational. Our reasoned analysis must pass through theories and analogies – yet a certain type of image provides the very condition of possibility of this process. Without these metaphors, it would be impossible to conceive of the universe and the activity of natural philosophy. So, rather than a subset of a larger analogical strategy, the machine is, in fact, the very precondition of that strategy.

We can also glimpse another tension between reason and imagination, understanding and corporeal figuration. The complex and imperceptible business of nature cannot be directly presented or represented to the senses, but only grasped through reason. The task of representation is to extract certain essential features from the tumult of matter and make them available to reason through the imagination. We shall return to this in a moment.

The wider, moral-theological dimension of Descartes' philosophy of knowledge is founded on the notion of the inscrutability of God. As Harry Frankfurt explains,

> The Church insisted that only God's word could authoritatively reveal the design of the world […], while Galileo maintained that this design could be discovered by the use of natural reason in scientific inquiry. Descartes, on the other hand, leaves God's truth to God and claims for science only a truth sufficient for man.[36]

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[34] Schouls P.A., *Descartes and the Possibility of Science* (Ithaca and London: 2000) 128.

[35] Schouls P.A., *Descartes and the Possibility of Science* 129.

[36] Frankfurt H.G., (1970) *Demons, Dreamers and Madmen: The Defense of Reason in Descartes'* Meditations (New York: 1970) 184.

Descartes saw the reconciliation of certain natural-philosophical and theological demands as crucial to the success of his system. In the words of Dennis Sepper, for Descartes '[t]he notion of God's absolute power undermines any significant analogy or proportionality between his being and that of his creatures.'[37] Our knowledge can never be absolute, or pretend to equal that of the Creator. The progress of philosophy may serve to enhance our sense of reverence for the Designer of the universe; indeed, this is one of the moral dimensions of Cartesian science. Yet this moral dimension is subordinate to the real mission of science, which is the betterment of the human condition (moral, bodily and material). Descartes advertises his project with the prospect of great utility and puts a passionate and persuasive case for the value of this collective enterprise.[38]

The mastery of nature requires a previous step: its representation. To put it simply, the task of natural philosophy is to manufacture representations that *work*. These representations must be understood in

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[37] Sepper D.L., *Descartes's Imagination: Proportion, Images, and the Activity of Thinking* (Berkeley: 1996), 215.

[38] In particular, in the *Discourse on Method*. Descartes maintains that these rational foundations must be laid by one person (i.e., Descartes himself), and hence the metaphors of architecture and town planning to refer to this aspect of his project. In what respects observation and experimentation, Descartes recognizes it is a collective task. The most eloquent expression is given in the following passage from the *Discourse*, which deserves to be quoted in full again: 'I believed that I could not keep them [i.e., the principles I had discovered] secret without sinning gravely against the law which obliges us to do all in our power to secure the general welfare of mankind. For they opened my eyes to the possibility of gaining knowledge which would be very useful in life, and of discovering a practical philosophy which might replace the speculative philosophy taught in the schools. Through this philosophy we could know the power and action of fire, water, air, the stars, the heavens and all the other bodies in our environment, as distinctly as we know the various crafts of our artisans; and we could use this knowledge – as the artisans use theirs – for all the purposes for which it is appropriate, and thus make ourselves, as it were, lords and masters of nature. This is desirable not only for the invention of innumerable devices of innumerable devices which would facilitate our enjoyment of the fruits of the earth and all the goods we find there, but also, and most importantly, for the maintenance of health, which is undoubtedly the chief good and the foundation of all the other goods in this life. For even the mind depends so much on the temperament and disposition of the bodily organs that if it is possible to find some means of making men in general more wiser and more skilful than they have been up till now, I believe we must look for it in medicine […] all we know in medicine is almost nothing in comparison with what remains to be known, and that we might free ourselves from innumerable diseases, both of the body and of the mind, and perhaps even from the infirmity of old age, if we had sufficient knowledge of the causes and all the remedies that nature has provided' (AT VI 61–3; CSM I 142–3).

the context of a view of knowledge as provisory, dealing in probable, working hypotheses:

> [...] although this method may enable us to understand how all the things in nature could have arisen, it should not therefore be inferred that they were in fact made in this way. Just as the same craftsman could make two clocks which tell the time equally well and look completely alike from the outside but have completely different assemblies of wheels inside, so the supreme craftsman of the real world could have produced all that we see in several different ways. I am very happy to admit this; and I shall think I have achieved enough provided only that what I have written is such as to correspond accurately with all the phenomena of nature.[39]

Again, the machine image demonstrates the very character of scientific activity. In this case, the metaphor of the clock (or rather two clocks) is closely associated with that of the craftsman. The function of this craftsman analogy is, in turn, two-fold, representing both God's and the philosopher's endeavour. While designing and making the world is the prerogative of the creator of the universe, the philosopher must find working models that allow more effective explanation and manipulation. In both cases the craftsman image encompasses a range of elements: the specific mindset of the technologist, activities such as designing, constructing, and empirical, on-the-spot problem-solving.

Laurens Laudan labels Descartes' general attitude as 'probabilism', and traces its influence on later natural philosophy, particularly in England.[40] According to Laudan, Descartes does not claim that the whole of natural philosophy can be deduced from first principles, and neither does he believe that truth in the sciences can be derived purely from empirical observation, unaided by any a priori or metaphysical suppositions. He advocates, instead, the hypothesising of principles of 'intermediate generality',[41] and despite his proscription to deduce physics from first principles, 'he never offers any deduction which does in fact exhaustively or uniquely explain some particular in terms of these very general principles.'[42]

These provisory images can be considered as 'morally certain', that is, 'as having sufficient certainty for application to ordinary life, even

[39] AT VIIIA 327, CSM I 289.

[40] Laudan L., "The Clock Metaphor and Probabilism: The Impact of Descartes on English Methodological Thought", in *Annals of Science* 22, 2 (1996).

[41] Laudan L., "The Clock Metaphor and Probabilism" 79.

[42] Laudan L., "The Clock Metaphor and Probabilism" 78.

though they may be uncertain in relation to the absolute power of God' (AT VIIA 327, CSM I 289–90). Our hypotheses must have technological efficacy in two senses:

(a) They must be able to address the internal, technical problems of the sciences, coherently explaining and integrating various observations, as well as solving issues of representation. As we shall see, these representations should aspire to clarity and economy and be closely in synch with the mechanisms of human perception and reasoning.
(b) These explanations must effectively guide the manipulation of nature for human ends. Their usefulness and 'fit' with reality must be confirmed by application.[43]

Things and thoughts, nature and our explanations, neither transparently reflect nor logically resemble each other. Knowledge (to define it negatively) does not adhere to a correspondence theory of truth. In the Cartesian schema, our ideas, opinions and observations must undergo an unforgiving methodical examination before they can be called 'knowledge', let alone truth. And the first obstacle to overcome is the illusory, misleading nature of our perceptions; a theme in which machine imagery also plays a defining role.

3. *Illusion, Appearance, the Automaton*

Descartes maintains that our sense impressions are confused and in no way resemble their objects. Yet they are congruent with them, in a manner to be examined soon. His model of perception is closely modelled on the machines of illusionism. This association of visual representation with optical illusion is crucial, and plays a role in the general distrust of sense perception that kicks off the process of hyperbolic doubt in the *Meditations*.

[43] Schouls writes: 'God, for Descartes, could have brought about certain effects in various ways, and our human faculties cannot reveal the way they were in fact brought about. However, if our scientific theory has as a consequence that it explains the effects we want to explain, or produces the effects we want to produce, then that *may have been* the way God in fact made things to work, and it is certainly a way in which things can and do work.' Schouls P.A., *Descartes and the Possibility of Science* 141.

The account of vision offered in the *Optics* and the *Treatise on Man* is based on the instruments and techniques of perspective representation. 'Perspective in art is an active, ongoing analogy for Descartes, not just a passing comment.'[44] The *Optics* is peppered with various analogies with engravings and perspective:

> For example, you can see that engravings, being made of nothing but a little ink placed here and there on the paper, represent to us forests, towns, men, and even battles and storms, even though, among an infinity of diverse qualities which they make us conceive in these objects, only in shape is there actually any resemblance. And even this resemblance is a very imperfect one, seeing that, on a completely flat surface, they represent to us bodies which are of different heights and distances, and even that following the rules of perspective, circles are often better represented by ovals rather than by other circles; and squares by diamonds rather than by other squares; and so for all other shapes. So that often, in order to be more perfect as images and to represent an object better, they must not resemble it.[45]

In *Man* Descartes uses the metaphor of painting to describe how light rays form a pattern on the retina: 'The change of shape that occurs in the crystalline humour allows objects lying at different distances to paint [*puissant peindre distinctement*] their images distinctly on the back of the eye.'[46] This image of an oval offers a counterpoint, at once contrasting and complementary, to the image of the big circle and little circle examined previously. Whereas in everyday perception we perceive a circle as an oval, reasoned knowledge must compare circles to circles.

For Descartes, as Maull writes, 'the only intelligible and true information to be had about bodies is geometrical.' To begin with, this requires establishing a distinction between a mechanistic explanation of the perception of *magnitudes* and that of *colours*;[47] to which we can add a third parameter: *intensity of light*, which gives the soul cues for degrees of shadow, light, and also textures. Descartes 'wanted the case

[44] Newell Decyk B., "Cartesian Imagination and Perspectival Art", in Gaukroger S.– Schuster J. – Sutton J. (eds.), *Descartes' Natural Philosophy* (London-New York: 2000), 478.

[45] AT VI 113. Descartes, *Optics* 60.

[46] AT XI 156, G 128. In addition, this metaphor appears in Kepler's *Paralipomena*, and is most likely the source for Descartes' own use. See Gorman M.J., "Projecting Nature in Early-Modern Europe" www.stanford.edu/~mgorman/ publications/ProjectingNature.pdf (Accessed 05/09/2005).

[47] Maull N.L., "Cartesian Optics and the Geometrization of Nature", in S. Gaukroger (ed.), *Descartes: Philosophy, Mathematics and Physics* (Brighton: 1978) 27.

for colour-perception to be very different from the awareness of figure.'[48] Whereas perceptions of size, distance, and shape (magnitudes) can be easily represented through projective geometry and perspective representation, other perceptual registers (such as colour, sound, and pain) imply a certain incommensurability between figure and judgement. In Discourse Eight of the *Meteors*, for example, Descartes develops an account of colour perception in terms of differences in the rotary motions of second element particles – that is, it arises from certain dynamical properties of matter. In the *Optics*, Descartes maintains that intensity of light is a result of the *force* of the movements in the brain, whereas colour is the result of their *character*.[49] In other words, colour bears an immediate causal relation to a physical/primary property. Intensity of light, on the other hand, seems an intermediary case: it implies a continuous transfer of force running from tendencies to motion to its translation into internal movements of fibres and spirits.

Size, shape, distance and *position* (or *location*), the four kinds of 'primary' information we obtain about objects, according to Descartes, are not 'proper' to sight, because our awareness of these arise later, as it were, in the brain. They are the result of the interaction of light and our perceptual system, rather than being causally contained in the qualities of matter. As such, they are relative to the observer and require a certain 'processing'; whereas colour derives from a primary quality and bears a more immediate relation to the idea it occasions (however difficult it is to picture this incommensurable leap).

Everything Descartes says about primary magnitudes can be understood in the context of perspective representation. The first striking feature of these parameters, as described in *Optics* and *Man*, is that they are static elements of composition. Descartes models visual perception on the analogy of someone looking at a picture. Once we subtract intensity of light and colour from an image, all we have left is a bare, schematic representation of edges, surfaces, and basic salient features, all of which could be theoretically constructed out of geometrical figures. Nowhere does Descartes explain the perception of *motion*, for example. We can reasonably assume that perception of motion arises from differential changes in these parameters; nonetheless the absence is telling.

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[48] Maull N.L., "Cartesian Optics" 29–30.
[49] Descartes, *Optics* 101.

Descartes applies geometrical means of representation to *relations* among points – the overall patterns that emerge from the transmission of pressures and tendencies to motion from the points at which rays of light are refracted by objects and transmitted to the eye, nerves and the machinery of perception. His diagrams and explanations focus on transversal figures, geometrical lines of action passing *across* the various realms involved in the perceptual process (light, surfaces, plenum, lens, etc.), as they would appear to an outside observer. These relations are macroscopic effects arising from the primary qualities of extension in motion, and their geometrical tractability confers a central status on various forms of mathematical diagrammation. Despite the fact that the brain is a three-dimensional object, and despite the figural complexity of the nerve openings, Descartes never really seems to abandon the notion of two dimensions, of traces on surfaces. This is because visual pictures are first received by the lens of the eye; the third dimension is only inferred from this information and from the fact that the eye must alter focus to look at nearby or faraway objects. The figures on the pineal and the ventricles are also two-dimensional.[50] Most of our ideas of position and distance are derived from *internal cues* of the body, such as muscle location, configurations of nerve openings, and the differential position of the eyes.[51] So, again, this information is not contained *in* the picture received by the eye.

Lastly, these four qualities are relative to the observer. Shape itself is a function of the edges and contours of an object as seen from a particular angle and is not a real feature of objects. The magnitudes are also relative to each other. Descartes, for example, writes that

> [...] the soul will be able to tell the size and all other similar qualities of visible objects simply through its knowledge of the distance and position of all their points, just as, conversely, it will sometimes judge their distance from the opinion it has of their size.[52]

Hall notes: 'A crucial feature of perception, whether of shape or distance, is comparison; perceptions are based on the drawing of distinctions.'[53] This fits squarely with the role of the observer in perspective

[50] In the *Regulae*, Descartes presents an early version of his theory of perception. The point is quite clear here: All sensory information is transformed into geometrical figures. In this early version, colour is also a geometrical pattern.

[51] Descartes, *Optics* 104–113.

[52] *Man*, AT X 160, G 133.

[53] In Descartes, *Treatise on Man* n. 106, 61.

representations, where the viewer is the ordering function of the pictorial elements, a fixed geometrical point grounding their relative positions.

By Descartes' time, the significance of perspective representation to optics had been amply recognized. Optical puzzles, for example, were of great interest to Kepler and Galileo. Besides, the mathematization of vision is inseparable from its instrumentalization, the becoming-machine of the eye. Perspective and illusionist representation is heavily dependent on the use of geometrical instruments, mirrors, grids and other artefacts such as the *camera obscura*. Newell Decyk argues that the Cartesian imagination itself can be understood as an instrument of this kind, 'a master mathematical decoder for various transformations of images.'[54]

The question is: how can we obtain certain (or at least reliable) knowledge from this elaborate deception? For Descartes, observation is based on surface appearances, while 'real' knowledge deals with the imperceptible business of inside mechanisms. Like touch, vision can only perceive *surfaces*. Descartes elaborates this point during an intricate discussion of transubstantiation in the Fourth Set of Replies:

> [...] I am convinced that what affects our senses is simply and solely the surface that constitutes the limit of the dimensions of the body which is perceived by the senses. For contact with an object takes place only at the surface, and nothing can have an effect on any of our senses except through contact [...][55]

Descartes reformulates the ancient battle between reality and appearance, truth and illusion, in terms of automata and illusionist machinery. There is a peculiar logic to the process of seeking explanations, a logic also based on the spectacle of machinery.

> I shall lay before your eyes the works of men involving corporeal things. After causing you to wonder at the most powerful machines, the most unusual automatons, the most impressive illusions and the most subtle tricks that human ingenuity can devise, I shall reveal to you the secrets behind them, which are so simple and straightforward that you will no longer have reason to wonder at anything made by the hands of men. I shall then pass over to the works of nature [...].[56]

[54] Newell Decyk B., "Cartesian Imagination" 474.
[55] AT VII 249, CSM II 173.
[56] *The Search After Truth*, AT X 505, CSM II 405.

Knowledge is conceived in terms of a spectacular demonstration, structured around a series of tensions or plays between appearance/reality, obscurity/clarity, wonder/knowledge, deception/truth, observer/observed, surface/inside, visible/invisible, spectator/stage, macroscopic/microscopic, and mind/body. Illusionist machines (by far the most common type in Descartes' writings) are the paradigmatic example of this logic; in particular, the lifelike automaton, a machine that simulates living things.

This pedagogical narrative has a temporal dimension comprised of two main stages. We begin in a state of wonder, the source of all philosophy. Wonder is a passion, a bodily affair before which the soul is passive. For a moment we forget we are watching a trick and become seduced by surface appearance, falling into the spell of the technological sublime.

Then there follows a process of unveiling and explanation: the banishment of wonder, as the conjurer-scientist comes to explain the mechanisms behind the trick. This is the final moment in the unmasking of appearance and comprises the main bulk of natural-philosophical activity.

The mechanical sublime is found in the context of a culture of wonder (admiringly documented by Daston and Park, and Stafford and Terpak,[57] among others) that emerged in Western Europe in the late medieval period. Descartes sought to incorporate these passions into natural philosophy, harnessing them for productive ends. In the words of Daston and Park: 'Descartes was wary of a sensibility of frozen astonishment and a science of nature that wallowed in secrets and rarities for their own sake'.[58] Wonder is not completely banished from Cartesian science; only a *certain kind* of wonder is undesirable: untamed, unreflective, confused wonder. As Galison says, Descartes tried to prove that '[e]ven if our naïve impressions were deceptive, our reasoned analysis of experience would be reliable.'[59]

Descartes conceives the automaton as an optical trick with an underlying rational structure – and this is precisely why it is such an attractive metaphor. As Dalia Judovitz writes: 'Illusion is presented as a

[57] Daston L. – Park K., *Wonders and the Order of Nature* 1150–1750; Stafford B. – Terpak F., *Devices of Wonder: From the World in a Box to Images on a Screen*, Getty Research Institute (Los Angeles: 2001).

[58] Daston L. – Park K., *Wonders* 292.

[59] Galison P., "Descartes's Comparisons" 318.

mechanical effect, whose optical-mathematical character underlies even its most fantastic and magical apparitions.'[60] Technologically produced illusion depends on a concrete, knowable set of mechanisms. Thus, the automaton (as a subset of the optical trick – in many ways, the ultimate piece of sensory trickery) plays both a positive and negative role, as both the model of confused wonder and the means for dispelling it.

But the philosopher-scientist is not merely a conjuror or trickster. The Cartesian scheme advocates more than a metaphysically uncommitted 'save the appearances' position. Certain kinds of representations provide an apter fit with reality than others. This is the foundation of what we may call Descartes' *other* method: not the deductive method advocated in his most famous work, but a philosophy that oversees the generation and application of analogies, pictures, rhetorical trickery, and the multifarious *technai* of scientific elucidation, explanation, promotion, and exposition.

Schouls argues that although 'throughout Descartes's works, from the most metaphysical to the most applied, there is the emphasis on utility', the philosopher always keeps his 'commitment to the ancient view that we live in a rational world as rational beings created by a rational God. It is the rationality of all three of these which guarantees in an a priori manner a potential fit between "fiction" and "fact".'[61] Our explanations may retain a certain fictitiousness, but 'to such 'fictions' there pertains nothing either nonrational or nonapplicable to our world.'[62] The rationality of this process rests on the notion of a *proportionality*[63] between the properties of matter, the figures in the brain, and the ideas in the soul. This law of representation rules over the tortuous path leading from matter to the judgments of the mind, all the way across the baroque perceptual system of the body-automaton. It ensures the rationality of this process, the congruence between perceptual (natural) representations

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[60] Judovitz D., "Vision, Representation and Technology in Descartes", ed. D.M. Levin, *Modernity and the Hegemony of Vision* (California: 1993) 65. Cavaillé coincides on this point: 'Ces machines optiques sont doublement paradigmatiques; de la vérité et de l'efficacité techniques de la science et tout á la fois du caractère fallacieux du monde visible' Cavaillé J.-P., *Descartes: La Fable du Monde*, Éditions de l'école des Hautes Études en Sciences Sociales, Librairie Philosophique J. Vrin (Paris: 1991) 47.

[61] Schouls P.A., *Descartes and the Possibility of Science* 142.

[62] Schouls P.A., *Descartes and the Possibility of Science* 141–2.

[63] The term is Sepper's, while Galison uses the term *congruence*. See respectively: Sepper D.L., *Descartes's Imagination*; Galison P., "Descartes's Comparisons" 320.

and world, and the value of scientific (artificial) representations (both as technical intervention and bearers of a certain truth).

Proportionality can be described as a metaphysical doctrine whereby each link in the chain nature-perception-cognition represents without resemblance.[64] This proportionality grounds the process of perception (particularly, visual perception), and also establishes the legitimacy (the 'apter fit') of the machine and its associated universe of representation. This ensures that, despite their largely illusory status, our perceptions are not merely arbitrary hallucinations but bear a consistent, logical relation to the world 'out there'. It also establishes a normative framework for scientific representations, which must act as 'natural' extensions of the cognitive apparatus.

4. *Machine Semiosis, or Proportionality at Work*

How is this proportionality obtained? One of the central Cartesian paradoxes, or ironies, is that the procurement of clear and distinct knowledge rests largely on a stupendously intricate illusionist apparatus. Descartes' system of perception can be pictured as a flow of patterned emissions: from object, to plenum, to common sense, to imagination. These patterns do not 'resemble' each other, but are nevertheless proportional or congruent. There are four main 'nodes' in the system, four figures that correspond point-to-point. T.S. Hall enumerates them: 'the pattern of the object, the pattern of the retinal image, the pattern of the projection of that image on the lining of the brain cavity, and the pattern of effluence of spirits through the surface of the pineal gland.'[65] The notion of a 'corresponding figure' does not necessarily mean that, say, the same image appears in the inside wall of the brain, like some kind of screen projection. The reach of the term 'figure' is quite vast, and Descartes takes it to mean 'anything which [...] can give the soul occasion to sense movement, size, distance, colours, sounds, smells, and other such qualities; and even things that can make it sense pleasure,

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[64] One of Descartes' culprits here is the theory of *imagos*, a popular thesis of medieval optics (derived from ancient sources) which maintained that objects emit a series of phantom images or resemblances. In the *Optics*, after introducing the analogy of the blind man, Descartes says: 'And by this means your mind will be delivered from all those small images flitting through the air, called intentional species, which worry the imagination of Philosophers so much' (Descartes, *Optics* 68).

[65] Descartes, *Treatise on Man* n. 132, 85.

pain, hunger, thirst, joy, sadness, and other such passions.'[66] It is clear that in all other cases of perception (touch, smell, hearing, etc.) the patterns of figures and pressures do not resemble their causes in the least. Vision follows the same principle also, but the process of translation, follows determinable technical rules. The figures that occasion perception need not resemble visual pictures. In the words of Wilbur Mackenzie, the relation is 'phenomenal' rather than representational.[67]

In *Man*, Descartes gathers all the explanatory resources of the engineering of his time and puts them at the service of a strange and original task: to build a brain according to purely mechanical, pneumatic, and hydraulic principles. Jean-Pierre Séris writes that the principle of this machine is 'the instantaneous communication of differences at a distance, by encodings and automatic translations which save or preserve diversity [...]' and 'the decoding of the world of physical phenomena according to a grid or alphabet or a sieve which restores its effects [...].'[68]

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[66] AT XI 176, G 149.

[67] MacKenzie A.W. "Descartes on Life and Sense", *Canadian Journal of Philosophy* 19 (1989) 163–192.

[68] Séris J.-P., "Language and Machine in the Philosophy of Descartes", in Voss S. (ed.), *Essays on the Philosophy and Science of René Descartes*, Oxford University Press (Oxford: 1993), 183. Descartes holds two different views of ideas. The first is corporeal, equated 'with patterned flows of animal spirits' (Grosholz E., *Cartesian Method and the Problem of Reduction*, Clarendon Press, [Oxford: 1991], 128). In this view, animals can also have ideas. The second notion of idea is more mental, and requires the soul. The ideas in later Descartes are severed from their dependence on corporeal objects, and the intellectual world is granted a high degree of freedom from the physical. Schouls argues that this position forces Descartes to put up purely intellectual correlatives of the mind's faculties (such as an intellectual imagination, and an intellectual memory). It appears that Descartes had to modify the 'corporeal' view after the sustained onslaught that followed his *Meditations*. Thus, in the Second Replies, the ideas are features of *conscientia*: 'I understand this term [i.e., idea] to mean the form of any given thought, immediate perception of which makes me aware of the thought. Hence, whenever I express something in words, and understand what I am saying, this very fact makes it certain that there is within me an idea of what is signified by the words in question. Thus it is not only the images depicted in the imagination which I call "ideas". Indeed, in so far as these images are in the corporeal imagination, that is, are depicted in some part of the brain, I do not call them "ideas" at all; I call them "ideas" only in so far as they give form to the mind itself, when it is directed towards that part of the brain' (AT VII 160–1; CSMX 152–3). Descartes' more considered view has ideas as features of the mental acts themselves, and not separable from the act of thinking, remembering, etc. So, there are two sources of ideas, one is an innate capacity of the mind, the other are the figures abstracted from experience during the process of perception. Charles Larmore attempts to reconcile these two views. For him the notion of 'idea' is quite broad in meaning, applying to 'any sort of representation, but chiefly the content of a

Apologising for the anachronism, Séris likens the inside of the Cartesian brain to an information machine, comparing the mechanism of brain figures to the workings of a punched card computer. Yet, the Cartesian brain is an analogue machine – inasmuch as it does not work on the basis of 'on/off' circuits, zeros and ones. The patterns on the inner walls of the brain are shifting diagrams of pressures and flows, openings and closings, pushing and pulling motions. The figures of the brain show a duality: their status as figures suggests the possibility of geometrical representation; yet the 'points' that make up these figures are openings of tubes, a mechanical process that stymies any efforts at precise description or visualization. The points have dimensions, and Descartes even confers explanatory power to the *degree* of their openness. The holes and pressures allow for indefinite degrees of variation; like a hand-operated dial, if you wish.

The imagination is a crucial locus of this whole process. Sepper succinctly explains how proportionality obtains between objects, imagination and ideas (using *phantasia* as the corporeal correlative of *imaginatio*, the imaginative faculty):

> Light, instantaneously transmitted, as an instantaneous pressure, preserves the geometrical pattern of the object it illuminates. This pattern is impressed in the sense organ [...] [and then to] the phantasia, where the geometrical pattern is reproduced. The mind, attending to this pattern in the phantasia, sees the object not as a geometrical pattern but as a yellow peach, by virtue of a 'language' of ideas corresponding to signals, a language instituted by nature.[69]

The imagination is central to figuration and representation. It is in the imagination (and its corporeal locus in the cerebral ventricles and the pineal gland) that Descartes places the figurative capacities of the intellect, the locus where we hold and construct (among other things) analogical relations. The possibility of truth-bearing analogies and models is ontologically grounded on extension, which is shared by phantasia (the organ of the imagination) and the world. Sepper argues that

> [...] one can develop extended, narrative hypotheses that will in essence imitate the real world because the ontological nature and mobility of the fable's material substrate (phantasia) is the same as that of space.

thought or a perceptual content' (Larmore C., "Descartes' Empirical Epistemology", in Gaukroger S. (ed.), *Descartes: Mathematics, Physics, and Philosophy* [London: 1980], 16).

[69] Sepper D.L., *Descartes's Imagination* 223–4.

> In another sense, however, this is not imitation or modelling at all: the likeness comes about as a result of the essential sameness of phantasia and external extension.[70]

In this space, I can imagine any motion that I want. Yet Cartesian science requires that the work of the imagination be limited by the understanding, rigorously guided by step-by-step deductions from incontrovertible principles (and, here, architectural metaphors come to Descartes' aid). In the words of Sepper, 'my imagining, in order to be truthful, must be guided by a few fundamental laws of motion that are not simply proper to the imagination.'[71] Descartes demands discipline in the imagination, the guidance of the intellect, especially at the stage 'where we look for power-bestowing knowledge in the development of science useful to us.'[72] The imagination must be reined in by the will and kept under the vigil of the sovereign intelligence. To imagine something, we must apply our volition; thus, the imagination must obey not only reason but also the will. Involuntary imaginings (such as dreams and daydreams) are occasioned *in* the body by the perturbation of the spirits (and they are, strictly speaking, *passions*).

From the corporeal imagination, figures are traced on the pineal gland, and interpreted by the incorporeal mind according to the algorithms of reason. Descartes locates the point of union between body and soul in this little gland, sitting at the centre of the brain ventricles and constantly emitting spirits. Different patterns on the walls of the brain prompt the spirits to flow in certain directions. It is the patterns on this gland, formed by the enlarging of its pores, which occasion sensations on the soul.

> Now among these figures, it is not those imprinted on the organs of external sense, or on the inside surface of the brain, that should be taken as ideas, but only those traced in the spirits on the surface of gland H [the pineal], where the seat of the imagination and the common sense is. That is to say, only these should be taken as the forms or images which, when united to this machine, the rational soul will consider directly when it imagines some object or senses it.[73]

This natural language of ideas, by which the mind decodes the patterns on the pineal gland, is beyond knowledge, representation and science.

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[70] Sepper D.L., *Descartes's Imagination* 229.
[71] Sepper D.L., *Descartes's Imagination* 220.
[72] Schouls P.A., *Descartes and the Possibility of Science* 136.
[73] AT XI 176–7, G 149.

Maull suggests that the language of the mind can be conceived as 'algorithmic' in nature.[74] The process of representation, then, must follow the meta-mathematical parameters of incorporeal reason – and this is the point at which reason must stamp reality with its own character, guiding the process of material figuration.

The mind is like the abstract mathematical point at which representation becomes judgment, the fulcrum that brings figuration under the reign of the *cogito*. In the *Meditations*, Descartes offers the famous example of a piece of wax to illustrate the limits of the imagination. He begins by describing a piece of wax in all its distinct sensory richness. Just taken from the honeycomb, it retains the taste of honey and the scent of the flowers. It is 'hard, cold and can be handled without difficulty; if you rap it with your knuckle it makes a sound.' But as soon as we put the wax close to the fire, all these qualities disappear. Colour, shape, size, smell – they all change. The wax goes from solid to liquid. Yet, the same wax remains.[75] The nature of the wax, Descartes concludes, is something 'extended, flexible and changeable.' The nature of this extension and changeability cannot be grasped by the imagination. The wax is capable of countless changes, and 'I am unable to run through this immeasurable number of changes in my imagination, from which it follows that it is not the faculty of imagination that gives me my grasp of the wax as flexible and changeable.' The perception of the wax is not a matter of the senses or the imagination, but of 'purely mental scrutiny'.[76]

Reason is necessary to grasp the complexities that transcend the figurable and lie beyond what can be represented in extension (and not only the complexities, but the most general and elementary *simplicities*: the very notion of figure, for example). I can *understand* the properties of a chiliagon (a figure of a thousand sides), but its figuration is beyond the capabilities of the imagination.[77] I can understand the notion of *figure itself*, regardless of this or that figure. Therefore, in the *Meditations*, Descartes says that the nature of the wax is perceived by the mind alone. 'I am speaking of this particular piece of wax; the point is even clearer with regard to wax in general.'[78]

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[74] Maull N.L., "Cartesian Optics" 30.
[75] AT VII 30, CSMII 20.
[76] AT VII 31, CSM II 21.
[77] AT VII 72, CSM II 50–1.
[78] AT VII 31, CSM II 21.

Reason and the imagination must constantly alternate in 'surrendering' to each other; and at certain stages in the work of science, reason itself will need guidance or discipline from empirical 'sensation and experimentation'.[79] So, 'proper' scientific method involves the close and reasoned coordination of the intellect, the imagination, and sensation (observation and experimentation).

However, the imagination has a large degree of independence, and as Véronique Fóti argues, its powers are fascinating and disturbing for Descartes. The imagination suggests a dimension of the mind that is obscure to consciousness, a power 'which threatens to disrupt the unity of the mind and to undermine the sovereignty of the intellect.'[80] As such, it carries an implicit danger as 'the fabricator of dreams which threatens to subvert the certainty of knowledge.'[81]

5. *Making a World*

Le Monde, ou Traité de la lumière (*The World, or Treatise of Light*), which Descartes began in 1629, was intended as a new summation of the universe intended to replace Aristotle's. From an account of the principles of light, Descartes set out to build a complete system of physics embracing all aspects of nature, including the heavens, the earth, winds, tides, rainbows, and living organisms. Light is the central thread of the treatise, weaving together diverse topics such as stars, fire, and human vision. Four years later, Descartes abandoned this work after learning of Galileo's conviction at the hands of the inquisition. It was published posthumously in two separate parts: *Traité du Monde* and *Traité de L'homme* (*Treatise on the World*, and *Treatise on Man*).

Both *World* and *Man* are part of the same cosmological thought experiment about the creation of a hypothetical world. The continuous narrative is an expression of the unity of Cartesian knowledge, namely cosmology, physics and biology. The passage from the inanimate physics of *World* to the physics of living things (in *Man*) also entails a shift of technological frames of reference. The main source for Descartes' mathematical physics was the engineering tradition of the day, particularly

[79] Schouls P.A., *Descartes and the Possibility of Science* 139.
[80] Fóti V., "The Cartesian Imagination", in *Philosophy and Phenomenological Research*, vol. XLVI, no. 4 (1986), 641.
[81] Fóti V., "The Cartesian Imagination" 637.

the Dutch tradition, to which Isaac Beeckham had introduced him. As Gaukroger shows, Descartes' physics 'would remain very dependant upon a hydrostatic/hydrodynamic model.'[82] In *Man*'s physiology a different technological universe enters the picture, a language concerned with pneumatics and mechanical components (to which we will return in a moment).

Man is an event of celebrated significance in the history of physiology, and it occupies a pivotal place in the cultural histories of technology and of the human body. In the life sciences, it marks the moment technology became central to the conceptualization of organic life as a complex mechanism subject to physical laws. Although the map of knowledge would shift and rearrange itself dramatically in the centuries to come, the early modern period cemented close and dense connections between the life sciences and the knowledge of the technologist.

The fable of *World/Man* can be considered a 'truthful imagining', building an imaginary universe from 'what is absolutely necessary to presuppose as existing in corporeal phenomena, the motion of parts.'[83] It is the freedom of the imagination that allows the introduction of fictitiousness, the elaborate theatre of *World/Man*'s fable – a striking instance of the use of the imagination for scientific purposes.

The subject of his work is light, Descartes announces at the beginning of *World*. And the first thing we must understand about light is that its real nature has nothing to do with how it appears to us. Descartes uses the metaphor of language and touch, where the lack of resemblance

[82] Gaukroger S., *Descartes: An Intellectual Biography* (Oxford: 1995) 225. Elsewhere (see Gaukroger S., "The Foundational Role of Hydrostatics" 60–80), Gaukroger argues that Descartes' model for physics was hydrostatics in cosmology, and statics in optics. Despite the founding principle of rectilinear momentum, Cartesian physics is concerned with *constrained* motion, since every single particle in the universe is constantly colliding and changing course. Whereas kinematics offered a geometrical model of bodies in motion but could not account for force, statics did the opposite: it traditionally dealt with bodies which forces were in a state of equilibrium, but could not account for motion or model it. Gaukroger shows that Descartes based his physics on statics, since each body in the Cartesian universe exists in a state of balance, the product of the various forces impinging on it. This leads him into some problems (indeed, absurdities), particularly in what regards his principle of rectilinear inertia.

[83] Sepper D.L., *Descartes's Imagination* 225. According to Sepper, for Descartes the imagination not only 'represents' but 'also shares the nature of the extension and mobility observed in the external world; thus it can produce a proportional copy of the original rather than a mere representation, and anything that transpires in phantasia can possibly exist in external extension as well' (228). The epistemological role of analogies, then, depends on the fact that 'any imaginative analogy is really a copy to scale of what does or might occur in the world' (228).

between sign (words, sensations) and referent (nature, world, ideas) is most obvious.

> Suppose we pass a feather gently over the lips of a child who is falling asleep, and he feels himself being tickled. Do you think the idea of tickling which he conceives resembles anything present in this feather?[84]

This theory of representation is the cornerstone of Descartes' epistemology. It is a semiotics inasmuch as it is a theory of signs, about the relation between sign and referent. As we have seen, it concerns mechanical mediation, the transmission of patterns across chains of mechanisms.

Following this principle of non-resemblance, the realm of the perceptual, bodily and experiential is displaced in favour of a strange image of the world. (In this context, analogies from familiar situations participate, somewhat paradoxically, in the defamiliarization of the everyday). In the first five sections of *World*, Descartes outlines his physical theory, in which the qualities and forms of bodies 'can be explained without the need to suppose anything in their matter other than the motion, size, shape and arrangement of its parts [. . .].'[85] Once these principles are in place, and properties such as hardness and liquidity have been explained accordingly, Descartes proposes to tell us a story:

> [. . .] in order to make this long discourse less boring for you, I want to clothe part of it in the guise of a fable, in the course of which I hope the truth will not fail to become sufficiently clear, and will be no less pleasing to see than if I were to set it forth wholly naked. [*Chapter 6 begins*]. For a while, then, allow your thought to wander beyond this world to view another world – a wholly new one which I shall bring into being before your mind in imaginary spaces. The philosophers tell us that such spaces are infinite, and they should certainly be believed, since it is they themselves who invented them. But in order to keep this infinity from hampering and confusing us, let us not try to go right to the end: let us enter it only far enough to lose sight of all the creatures that God made five or six thousand years ago; and after stopping in some definite place, let us suppose that God creates anew so much matter all around us that in whatever direction our imagination may extend, it no longer perceives any place which is empty.

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[84] AT XI 6, CSM I 82.
[85] AT XI 26, CSM I 89.

> Even though the sea is not infinite, people on some vessel in the middle of it may stretch their view seemingly to infinity; and yet there is more water beyond what they see.[86]

Secure foundations for knowledge must be sought somewhere else, away from the illusory evidence of the senses. But (another paradox) in *World* this search for solid foundations involves a journey into a highly imaginative mind-space, a faraway land; while in *Man* we descend from these cosmological heights into a mechanical microcosmos, a virtual double of the human-animal body.

Thus, to understand how the world really is, independent of our subjective impressions, it is necessary to undergo a reasoned experiment: to imagine ourselves in another world that is also our world. In a way, this invented space is more real than our world, for it is a world bereft of appearance. Yet at the same time it is *pure appearance*: a fable, a mechanical theatre. All the secrets of nature, the invisible mechanisms of her marvellous machines, are open to our vision, to total knowledge. We can witness how the planets are formed, how vortices arrange themselves to compose the solar system. We can travel down to the microscopic realm of bodily phenomena and watch, for example, how food is tasted and digested.

Descartes employs the conventions of myth and fable with an ironic distance, as a pedagogical metaphor. His use of myth is reminiscent of the way Parmenides employed religious poetry more than two thousand years before, turning the language of *mythos* against *mythos*. Ortega y Gasset's remarks on Parmenides can easily also apply to Descartes, since both philosophers drew on canonical religious myth of their time while 'no longer believing in it, as mere instrument of expression, that is, as vocabulary. Defunct beliefs endure a long time transformed into mere words. Once dead, mythology shows a terrible tenacity.'[87]

But the context has changed. Descartes' production resonates with the spirit of the baroque, a period enamoured with the notion that the world is a stage and life an illusion. Descartes' tale is also informed by other, real theatres: theatres of anatomy, the machinery of stage

[86] AT XI 31–33, CSM I 90.

[87] Ortega y Gasset J., *Origen y Epílogo de la Filosofía* (Madrid: 1967) 134. Translation mine.

production, and mechanical spectacles, as Jean-Pierre Cavaillé has comprehensively shown.[88]

This fable is a mechanical production allowing us a peek at the elaborate machine that sustains the spectacle behind the stage. Descartes deflects potential clashes with doctrine (in particular, the account of creation in Genesis) by emphasizing the speculative nature of his tale. If things have followed a different process in this imaginary world, this is just for the sake of exposition, to help us understand the world better by following how it came about.[89] However, there is a clear impression that Descartes intended *World* to be an account of how things really happened. If God created a world anew by infusing motion within a block of inert substance, this world would be the same, for 'God is immutable and [...] acting always in the same way, he always produces the same effect.'[90] As Bitbol-Hespériès shows, Descartes alternates regularly between the expressions 'real world' and 'new world', using these exactly the same number of times throughout the text.[91] Similarly, in *Man*, the assertion that living bodies are *nothing but* machines must be taken in the most literal way – despite the outrageousness of his imagined automaton. The oscillation between imaginary and real, metaphor and literality, is pivotal to Descartes' line of attack. Moreover, Descartes puts this rhetorical strategy, this enigmatic textual play of mirrors, to great use. *World/Man* is a fertile scientific fiction that

[88] Cavaillé J.-P., *Descartes: La Fable du Monde*.

[89] In Part Five of the *Discourse*, Descartes explains his choice of mode of exposition: 'Yet I did not wish to infer from all this that our world was created in the way I proposed, for it is much more likely that from the beginning God made it just as it had to be. But it is certain, and it is an opinion commonly accepted among theologians that the act by which God now preserves it is just the same as that by which he created it. So, even if in the beginning God had given the world only the form of a chaos, provided that he established the laws of nature and then lent his concurrence to enable nature to operate as it normally does, we may believe without impugning the miracle of creation that by this means alone all purely material things could in the course of time have come to be just as we now see them. And their nature is much easier to conceive if we see them develop gradually in this way than if we consider them only in their completed form' (AT VI 61–3, CSM I 142–3).

[90] AT XI 43, CSM I 96.

[91] 'L'alternance, du reste parfaitement équilibrée dans la suite du texte entre les expressions «nouveau monde» et «vrai monde», est significative: huit occurrences pour «nouveau monde», huit également pour «vrai monde», qualifié en outre, à deux reprises, d'«ancien monde».' Bitbol-Hespériès A. – Verdet J.-P. (eds.), *Le Monde, L'homme* (Paris: 1986) xxxi.

sidesteps confrontations with religious and intellectual authorities and the need to provide observational and experimental corroborations, while making the exposition 'less boring', promoting Cartesian philosophy in a didactic and engaging manner.

At the beginning of *Man*, when the time comes to speak of the creation of humans, Descartes writes that the hypothetical men of his tale are composed of a body and a soul, and that each is to be treated separately. He continues:

> I suppose the body to be just a statue or a machine made of earth, which God forms with the explicit intention of making it as much as possible like us. Thus He not only gives its exterior the colours and shapes of all the parts of our body, but also places inside it all the parts needed to make it walk, eat, breathe, and imitate all those functions we have which can be imagined to proceed from matter and to depend solely on the disposition of our organs.
>
> We see clocks, artificial fountains, mills, and other similar machines which, even though they are only made by men, have the power to move of their own accord in various ways. And, as I am supposing that this machine is made by God, I think you will agree that it is capable of a greater variety of movements than I could possibly imagine in it, and that it exhibits a greater ingenuity than I could possibly ascribe to it.[92]

Descartes offers an account of digestion, the formation and circulation of the blood, the actions of the heart, breathing, and other bodily processes; then proceeds to describe the brain and the mechanisms behind animal-human perception. The reach of the mechanistic paradigm is ambitious and vast. At the end of the treatise, Descartes invites the reader to consider all the functions he has ascribed to this machine:

> the digestion of food, the beating of the heart and the arteries, the nourishment and growth of the bodily parts, respiration, waking and sleeping; the reception of light, sounds, odours, smells, heat, and other such qualities by the external sense organs; the impression of the ideas of them in the organ of common sense and the imagination, the retention or imprint of these ideas in the memory; the internal movements of the appetites and the passions; and finally the external movement of all the bodily parts [...] and in this they imitate as perfectly as is possible the movements of real men.[93]

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[92] AT XI 120, G 99.
[93] AT XI 202, G 169.

The passage from the physics of matter into the theory of life is seamless. The same principles apply to cosmic fluids and animal spirits; the same metaphysics embraces the animate and inanimate. The continuous narrative expresses the unity of Cartesian knowledge, traversing astronomy, physics, biology, and technology.

The mechanical spectacle comes to act as a framing metaphor, taking on a similar function to that of the fable of *World*. The text, images and diagrams of *Man* are like a surrogate of the theatrical machinery, assembling together an aggregation of mechanical processes and components into a strange but coherent picture of a fictitious machine.

The mechanical theatres that had become fashionable with the nobles of renaissance Europe during the fifteenth and sixteenth centuries were a direct source of inspiration for Descartes. The art reached its peak first in Italy. The garden theatres consisted of an arrangement of terraces and grottoes where the spectator could wander at leisure. The spectacle included singing mechanical birds, moving statuary, automated organs, trumpets, ornate water fountains, and mythological scenes enacted by large numbers of self-moving figures.

One of the most lavish and accomplished creations in this vein was the Royal Château of Saint-German-en-Laye, which Descartes most likely visited between the summer of 1614 and the autumn of 1615. The description in *Man* is consistent with the grotto of Orpheus:

> Now as these spirits enter the cavities of the brain, they also pass in the same proportions from there into the pores of its substance, and from these pores into the nerves. And depending on which of these nerves they enter, or even merely tend to enter, in varying amounts, they have the power to change the shapes of the muscles into which these nerves are embedded, and in this way to move all the limbs. Similarly, you may have observed in the grottoes and fountains in the royal gardens that the force that drives the water from its source is all that is needed to move various machines, and even to make them play certain instruments or pronounce certain words, depending on the particular arrangements of the pipes through which the water is conducted.
>
> And the nerves of the machine that I am describing can indeed be compared to the pipes in the mechanical parts of these fountains, its muscles and tendons to various other engines and springs which serve to work these mechanical parts, its animal spirits to the water that drives them, the heart with the source of the water, and the brain's cavities with the apertures. Moreover, respiration and similar actions which are normal and natural to this machine, and which depend on the flow of spirits, are like the movements of a clock or mill, which the normal flow of water can make continuous. External objects, which by their mere

> presence act on the organs of sense and thereby cause them to move in many different ways […] are like strangers who on entering the grottoes of these fountains unwittingly cause the movements that take place before their eyes.[94]

In the late sixteenth century, King Henry IV enlarged the Château with the aim of turning it into the main royal residence. For this purpose, he enlisted the talents of Tommaso and Alessandro Francini, who set to work in 1598 to install a series of grottoes and fountains in the layered terraces separating the Seine River from the residence. Francini later installed waterworks for King Louis XIV at the palace of Versailles. A contemporary visitor to St.-German (André Du Chesne) recorded the scenes in these grottoes:

> There is a nymph standing in half-relief with a laughing face, beautiful and gracious, who allowing her fingers to be moved by the movement of the water, plays on an organ. Near the window is a statue of Mercury with one foot in the air and the other placed on a support, noisily sounding and intoning a trumpet. The cuckoo is heard and recognised by his song. On the way out […] a fierce dragon is encountered who beats his wings with great vehemence, and violently belches forth huge mouthfuls of water. The dragon is accompanied by various little birds, which truly seem not painted or imitated by alive, fluttering their wings, making the air echo with a thousand warblings, and above all, the nightingales singing very beautifully in several choirs.[95]

Another contemporary, after praising the skill of the mechanician, expressed his contempt at the bad taste of 'this gim-crack ironmongery'.[96] In these displays, the observer wandered through a series of tableaus, mechanical spectacles, ornate water features, etc. The spatial layout structured the experience. Knoespel points out: 'As the observer moved through the new renaissance gardens, he simultaneously undertook an allegorical journey based on established mythographic stories and encountered an array of new technological devices that challenged him to a new awareness of technology.'[97] The fountains in these gardens, Simon Schama writes in *Landscape and Memory*,

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[94] AT XI 130–1, G 106–7. The passage goes on to describe an automaton of a bathing Diana who hides in the reeds as soon as the visitor approaches; if the visitor gets closer, a Neptune steps forth threateningly with his trident.

[95] Chapuis A. – Droz E., *Automata: A Historical and Technological Study* (London: 1958) 44.

[96] Chapuis A. – Droz E., *Automata* 47.

[97] Knoespel K.J., "Gazing on Technology: *Theatrum Mechanorum* and the Assimilation of Renaissance Machinery", in Greenberg M. – Schachterle L. (eds.), *Literature*

> were conceived as stations en route to illumination often connected by lines of water that mapped the progress of the visitor along a strictly predetermined and allegorically saturated path. That path was thus transformed into a river-road itself, navigated with the help of mythological and poetic references.[98]

These places, Schama adds, were not designed for 'casual strolls', and the visitors were expected to be literate in a variety of classical texts (Ovid, Virgil, and compilations of pagan myths). Besides this ambulation, the gardens require no physical involvement, save standing and watching, and walking to the next exhibit.

In technical terms: 'Little change and no improvement had taken place in these mechanisms since the time of Hero.'[99] The main motive forces of these automata were weights, water and simple pneumatic principles, conveyed in pulleys, ropes, gears, water wheels, reservoirs and pipelines. Yet their ingenious combination achieved spectacular results. And incrementally these designs became more ambitious. As Knoespel suggests above, these machines drew attention to their own artificiality, directing wonder at the power of human art.

Like these automated displays, the body-machine of *Man* is an instructive spectacle. The treatise imagines a supplementary moment to the wonder experienced in these gardens; Descartes unveils the mechanisms, takes the reader on a behind-the-scenes tour of what makes the automata move. The ambulant spectator walking through the paths and grottoes is transformed into a non-located, omniscient observer. The assemblage of text and images becomes a technologically enhanced eye, born of the science-fiction marriage of microscopy and mechanical simulacra. As Jean-Claude Beaune says, 'the automaton is a spectral model, a sort of *theoretical microscope* enabling a 'sighting of depth': the anatomy and the internal movements are seen across the corporeal envelope, supposedly negligible, as one would see the wheels of a machine.'[100] Both microscope and automaton materialize the spectacular play of visibility and invisibility, surface appearance and inside mechanisms: the logic of illusion that animates Descartes' theory of life and knowledge.

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and Technology (London and Toronto: 1992) 112.

[98] Schama S., *Landscape and Memory*, Harper Collins Publishers (London: 1995) 275.

[99] Chapuis A. – Droz E., *Automata* 41.

[100] Quoted in Judovitz D., *The Culture of the Body: Genealogies of Modernity* (Ann Arbor: 2001) 77.

In an important sense, *Man* is a technological treatise, doing as much for engineering as for anatomy or physiology. Although the body-machine follows the same principles as the rest of Descartes' physics, it allows a considerable expansion of the explanatory resources of mechanism. It is not until we enter the body that we can experience the full poetic potential of the machine, as Descartes deploys an astonishing array of mechanical-analytical elements (rods, bellows, valves, pulleys, tubes, levers, sieves, counter-weights and wheels), machines (organs, self-moving statues, fountains, clocks, mills), principles of work and sources of power (water, air, weights, levers and balances, pressures and collisions), and technical processes (distillation, sieving, impressions on cloths) to assemble a see-through model of a lost flesh-and-blood original.[101]

Occasionally, one-to-one analogical connections (A:B::C:D) are established between specific, known mechanisms and organic processes. However, what matters to Descartes is not this or that machine, but the laws of all machines, the very ontology of machines. The *logos* of technics comes to gather the most disparate devices and technical practices. Descartes anticipates modern notions of technology as a rational discourse that organizes and systematizes scattered bodies of knowledge and things. The Cartesian body-automaton is an attempt to integrate heterogeneous technological experiences into a single corpus of knowledge: a 'universal mechanics'. Disparate bodies of knowledge such as metallurgy, the building of pipes and conduits, the craft of making scientific instruments, can now share a common foundation. Descartes' gesture is more programmatic than practical and is influenced by the vibrant tradition of machine treatises of his day. In many ways, *Man* announces the engineering branch of the Cartesian dream of a universal mathematical physics.

As Carl Mitcham argues, one of the main differences between ancient conceptions of *techne* and modern technology is their respective ontologies of matter.[102] Although Plato and Aristotle, for example, conceived of craftsmanship in different terms, for both of them the raw matter and procedures of *techne* entailed dimensions that escaped rationaliza-

[101] Catherine Waldby's notion that biomedical images are produced "through a sacrifice of their referent" is suggestive in this context. See Waldby C., *The Visible Human Project: Informatic Bodies and Posthuman Medicine* (London and New York: 2000) 36.

[102] Mitcham C., *Thinking Through Technology: The Path Between Engineering and Philosophy* (Chicago: 1994) 131–2.

tion. Both Plato's divine craftsman and Aristotle's nature had to work with the pre-existing qualities and potentialities of substances. What's more, for them technical activity was goal-oriented and could not be considered separately from its ends. Mitcham argues that this is one of the reasons there are no treatises on *techne* in the Greek tradition, with the notable exception of Aristotle's *Rhetoric*.

The ready-made virtual automaton of *Man* confronts us not merely with collisions of particles, but with a highly ordered arrangement of mechanisms and materials; a universe of meshes, threads, conduits, cavities, sieves and patterns of little holes. Descartes' innovation is to show us not just inert arrangements, but structures in motion – a kind of virtual cinematic tour of a living body that pushes to the limit the visual and conceptual tools of anatomy and the technological treatise. In the centuries that followed, the conceptual procedure of breaking things down into elements and chains of mechanical action developed its social counterpart in the organization of labour and industry, a crucial area of endeavour as European empires gained economic and cultural ascendance.

Descartes' conception of technology is also modern because it removes the theological injunction that separated art and nature, and human skill from the supreme artistry of God. Descartes prescribes no theoretical limits to the technical activity of humans. As such, this wondrous mechanical fable about our bodily interior can be seen as a poem to the possibilities of human ingenuity, told by way of a journey through an imaginary machine.

6. *Making Pictures: Setting the Imagination into Action*

Man is extraordinary in terms of the techniques of representation it deploys and the demands it makes on the imaginative capacities of the reader. The operations of text, image, imagination and reason are closely coordinated, creating an unparalleled experience.

The illustrations ('figures') of *Man* seek abstraction and simplicity and occupy a halfway point between sensory qualities and the language of the ideas. The structure of the body must be made visible and comprehensible in terms of schematic elements and relations between motions and figures. In *Man*, anatomy aspires to the condition of mechanics. In her study of this treatise, Rebecca Wilkin argues that, as products of the imagination, figures are 'the form of thought that manipulates

sensual data [...].'[103] Figures are 'expository schema that give shape (and credence) to truths deduced through reason.'[104] As Clerselier, editor and publisher of the French edition, pointed out: 'it is up to reason alone to make known those [things] that are too subtle to submit to the senses [...].'[105] But rather than an inert series, the text-image assemblage of *Man* animates these figures and presents them to the imagination as a contraption in motion. The body-automaton is alive, and we can follow it in action, its insides open to our gaze.[106]

A distinct product of the sixteenth century is what Knoespel calls a 'cultural fascination with the visual staging of knowledge [...]'.[107] This period witnesses the application of novel pictorial styles and techniques across diverse areas of endeavour. Says Catherine Wilson: 'Reading documents of the period, one is repeatedly struck by references to seeing, and seeing for oneself – to widening the horizon of visual experiences by direct acquaintance with objects or with the help of pictures and models.'[108] As Michel Foucault notes, the visual paradigm was closely joined to the order of discourse, establishing the transparent transcription from vision into language and allowing 'the visibility of the animal or plant [*and we might add here* 'or machine'] to pass over in its entirety into the discourse that receives it.'[109] It is in this context that we should understand the dense web of cross-references images and text in *Man*.

In its zeal for encyclopaedic knowledge, technological treatises gathered together various technical dimensions (military, urban, industrial, entertainment, etc.) into works that applied uniform regimes of visual and textual representation.[110] Similar representational styles and formal-

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[103] Wilkin R.M., "Figuring the Dead Descartes: Claude Clerselier's *Homme de René Descartes* (1664)", *Representations* 83 (2003) 44.

[104] Wilkin R.M., "Figuring the Dead Descartes" 49

[105] Quoted in Wilkin R.M., "Figuring the Dead Descartes" 53.

[106] The perspective is that of a disembodied 'total optical system' (Kember, cited in Waldby C., *The Visible Human Project* 5). Both modern imaging technologies, and early modern anatomical atlases are based on procedures 'for transforming the volumetric bulk of the singular, locatable corpse [or living body] into a readable, and hence writable, object' Waldby 58.

[107] Knoespel K.J., "Gazing on Technology" 100.

[108] Wilson C., *The Invisible World: Early Modern Philosophy and the Invention of the Microscope* (New Jersey: 1995) 24.

[109] Foucault M., *The Order of Things: An Archaeology of the Human Sciences* (London: 1970) 135.

[110] The most important works were: Agricola, *De re metallica* (1557); Agostino Ramelli, *Le diverse et artificiose macchine* (1588); Jacques Besson, *Theatrum instrumentorum et machinarum*

isms traversed various domains, applied to geographical spaces, buildings, machines and bodies. According to Sawday, 'the visual rhetoric with which the illustrators of both the machine books and anatomy texts worked was a shared system.'[111] In the words of Sawday, machine books 'opened up a world of *interior* mechanical invention which was analogous to the interior world which the magnificent Vesalian and post-Vesalian books of anatomy laid before their wealthy readers.'[112] But whereas in anatomy this peeling away had a concrete referent in the practice of dissection, the representation of technology posed some different challenges, such as picturing force or direction. Anatomy is '*par excellence* a descriptive science' where 'the visual representation acts as a surrogate for the eye-witness experience or as a visual summation of many eye-witness experiences.'[113] In technological treatises, on the other hand, the reader must learn a range of specific visualization techniques. It is necessary to imagine how the machine works, how it moves, and how the parts slot together. As a result, renaissance and early modern illustrations of machines are often equal parts drawing and diagram. Technological treatises also depicted actual objects both in their appearance and inner workings; also, they portrayed many *invented*, possible (and impossible) machines.

Rather than a collection of plates of different machines (or a succession of individual bodies and parts, as in Vesalius' treatise), *Man* studies the same machine from a number of perspectives, as a complex

(1569) Vittorio Zonca, *Nuovo teatro di machine et edifici* (1607); and Salomon de Caus, *Les raisons des forces mouvantes avec diverses machines tant utiles que plaisantes ausquelles son adjoints plusioeurs desseigns de grotes et fontaines* (1615).

[111] Sawday J., "Forms Such as Never Were in Nature': the Renaissance Cyborg", in Fudge E. – Gilbert R. – Wiseman S. (eds.), *At the Borders of the Human: Beasts, Bodies and Natural Philosophy in the Early Modern Period* (London: 1999) 178.

[112] Sawday J., "Forms Such as Never Were in Nature" 178. Among these we can cite: techniques to produce the illusion of three-dimensional space and volume (such as shading); the cut-away view, the exploded and transparent views; the convention of letters indicating elements of the drawings to allow cross-referencing with the text (pioneered by Leonardo, and appearing first in anatomical contexts before migrating to the machine context); and the theatrical stage as framing metaphor. Pictures in both contexts perform a kind of analysis we may term 'elementary decomposition', considering the body or machine as an aggregate of interlinked components that can be disassembled and subjected to taxonomical classification. This is the historical beginning of one of the most decisive analytic and representational tools of machine design, which would later develop into attempts at a universal grammar of machine components (such as the 'mechanical alphabet' of Christopher Polhem at the end of the seventeenth century, later systematized by Carl Johan Cronstedt).

[113] Kemp M., "Vision and Visualisation" 19.

amalgamation of systems and mechanisms. Descartes' innovation is to show us not just inert arrangements, but moving structures, a kind of cinematic tour that pushes to the limits the available technologies of representation.

In its complex imaginary deployment, the machine image invokes two complementary but relatively autonomous modes of representation, which we may call the *geometrical* and the *micromechanical*. Descartes' theory of vision combines these two approaches most clearly. Rays of light are rectilinear tendencies to motion transmitted through the plenum. As they reach the eye, they are refracted and refocused into points of pressure, tracing patterns at the back of the eye. The lines and figures of geometry are applied to the modelling of physical effects. Light rays are (geometrically speaking) straight lines that (physically speaking) do not exist as such, but arise from tendencies to motion traversing the plenum.

At the moment the pressures at the back of the eye are communicated to the brain through the tubes, we leave the language of images (an optic-geometric paradigm) to enter the machine proper (pneumatics and mechanics). From the neat figures of light rays, we enter the cavernous industry of the brain, a frantic and bustling world of collisions, motions, vortices, fluids and particles in constant agitated interaction. The break is clearly visible in the figures of *Man* and *Optics*. There are a vast number of filaments in the optic nerves corresponding to each point of the image; different patterns of pressure pull different fibres, enlarging the openings in the brain and thus forming different figures inside it.

On one hand, we have figures, patterns, and the pictorial representations of geometry. On the other, we have motions, collisions and the affairs of matter. The physical motions of light obey laws that are geometrically expressible, since tendencies to motion follow rectilinear paths between points. But as soon as we enter the optic nerves, the geometrical diagram gives way to the anatomical/technological illustration, concerned with the visualizable structures of organisms and machines. The illustrators of *Man* juxtapose these two modes of representation in the same picture, a hybrid that instantiates and enacts the machine metaphor to a hitherto unseen degree.

These two modes of representation correspond not only to two traditions of illustration, but also to two phenomenological registers. At the biomechanical level, the machine metaphor has a strong *tactile*

component, involving images of pulling, pushing, sieving, pressing, tensions, agitations, flows, and other physical actions that may not be readily visualized, but have an affective basis on bodily experience. Moreover, the visual is ontologically subordinate to touch, of which it is a special case. Images in Cartesian epistemology, as we have seen, do not have any cognitive value, and '[w]hat is transmitted by the physical processes leading up to the sense organ [...] is motion or pressure, not an image.'[114] In both the *Dioptrics* and *Man*, the paradigm of vision is blindness.[115] The value of this analogy is that, for the blind man, there is clearly no resemblance between experience and its physical referents. There is a yawning abyss between the real properties of the world and the world as is present to our perceptual awareness. This makes possible the displacement of the phenomenological immediacy of visual perception in favour of geometrical thought and a heuristic regime where analogy and the imagination must come under the aegis of reason.

Since matter is indefinitely divisible and the machines of nature unimaginably complex, the explanations of *World* and *Man* are always pushing the limits of what can be meaningfully visualized. Descartes is constantly reminding us of the indefinite complexity of matter in motion, of which both geometric and mechanical elements are rather emblematic stand-ins. A considerable region of activity remains *beyond* visual, geometrical and textual representation ('you may reasonably think it capable of a greater variety of movements than I could possibly imagine in it, and of exhibiting more artistry than I could possibly ascribe to it.')[116] Simple lines and diagrams come to represent the unimaginable activity of corporeal patterns, bodily flows, and natural processes in general. The complexity of the body-machine can be grasped in the most abstract of manners; the way we understand a chiliagon, for example. The complexity is not only spatial (too small or large), but temporal: these figures flicker and combine at amazing

[114] Sepper D.L. *Descartes's Imagination* 218.

[115] The analogy of blind man is an old one, and not Descartes' original invention. Meli points out that it occurs in 'Simplicius's commentary on Aristotle's *De anima* and in *Liber de oculis*, attributed to Galen and included in different Latin editions of his work.' Gassendi also referred to it in his *Syntagma Philosophicum* (Meli D.B. "The New Anatomy of Marcello Malpighi", in Meli D.B. (ed.), *Marcello Malpighi: Anatomist and Physician* (Firenze: 1997) 42.

[116] AT XI 120, CSM I 99.

speeds well beyond the reach of perception. What is remarkable about the Cartesian representational machine is how it lets us perceive or *feel* this bustling complexity, just outside the reach of the imagination.

7. *Conclusion*

It is my hope that this essay has made a contribution to a better historical understanding of the scientific revolution; in particular, in establishing how technology and science entered into dialogue, transforming each other, becoming productive and constitutive of each other. Descartes' use of technological metaphor can be modelled as the meeting of two transversal lines. On one hand, we have the *techne* of discursive reason: a number of analogies, models, metaphors, comparisons, images, etc. On the other, a plethora of machines, techniques, instruments, artefacts and technocultural forms. Machine imagery does not always have a simple analogical function, but enters Cartesian natural philosophy in complex and much more fundamental ways. Technology itself also spills in other directions as well, associated with myriad meanings, and embedded in various cultural contexts and forms (articulating, for example, themes such as wonder, the theatre, fable, illusion and error). As we have seen, the meeting of these two threads can be taken as a single line of inquiry, as a consistent strategy that cuts across various aspects of Descartes' thought. Indeed, it could be argued that the machine metaphor ties together the whole of Descartes' natural-philosophical project – especially if we consider the machine not just as an isolated group of metaphors but as a kind of *meta-analogy*: an overarching image that sustains Cartesian metaphysics. Etymologically, the very notion of machine supports this understanding: *machina* also means 'framework', or scaffolding. Thus, it becomes impossible to construe Descartes' metaphysics without attention to the 'machine': the abstract conceptual structure that not only *results from* this multifarious activity, but also constitutes its point of origin, its condition of possibility. There are a number of directions we can go from here, and what follows is a rough sketch of some possible conclusions.

One of the features of early modern science, as we have mentioned, is an explosion of metaphor, as new worlds were made visible and new explanatory frameworks tried out. What is peculiar to the machine metaphor (by far the most important class of metaphor in this period) is that it later disappears, becoming a tacit, implicit assumption. For

modern science, the assumption that the world and living organisms are machines becomes commonplace, an invisible, high-order structure that frames more specific, local projects. As the technological apparatus of scientific experimentation grew in density and complexity, so did the metaphor of natural things as artefacts grow to become embedded in material set-ups, no longer needing to be explicitly articulated. A single plenum connects the natural and the technological. Of course, the metaphor has meant a number of things, not all of them compatible. For example, the machine could accommodate both a plenarist metaphysics and a metaphysics that admitted vacua. Leibniz's use of the image was totally different to, say, Hobbes'. But even people who opposed the mechanistic conception had to engage with the machine image, if only to point out its shortcomings.

In fact, the machine image resurfaces precisely when its status as a high-order assumption is brought into question (e.g., the debate between vitalism and mechanicism). Descartes' use of the metaphor is illuminating inasmuch as it allows us to glimpse how this high-order assumption was set in place, how it had to be forcefully worked into the fabric of philosophy and science. This is what makes *Man* such an interesting piece of work: it suggests the machine hypothesis was outrageous and unworkable.

With Descartes, the machine image became starkly literal. It did not arise out of an attempt to find the best theory to suit the data, or as a hypothesis providing a common ground for disparate observations; it entered the theatre of metaphysics as a device of the imagination, an idea that had to be grasped more in terms of its potential than any concrete scientific attainment. The world-machine was not only an intermediary hypothesis, but a categorical and literal statement of practical identity. It was both heuristic device and ontological thesis. In the centuries that followed, machine imagery became central in the conceptualization of organic life as a complex mechanism subject to physical laws. Descartes set the metaphysical conditions of possibility for the merging of organism and machine in a range of industrial, military, medical and scientific contexts. The first attempts to compare the cavities of the brain to a wind-powered musical instrument, or the human nervous system to a hydraulic puppet might strike the modern reader as surreal or downright comical. The machine image was, in many ways, a clumsy and unworkable metaphor, often counter-intuitive, and in some cases (such as with LaMettrie or d'Holbach) blatantly offensive. Furthermore, it struggled through massive difficulties in what we would

now call biology and organic chemistry, in trying to explain chemical phenomena such as fermentation and combustion, and vital processes such as growth and generation. In Gabbey's words, the mechanists 'tried to explain everything, which was too much by a long chalk.'[117]

But from these humble and unlikely beginnings, this odd notion (that all natural phenomena, including ourselves, can be understood in the light of technical objects and activities) has become pervasive, commonsensical even, and one of the fundamental myths of our age. It not only affected profoundly the outlook and practice of modern science, but also the social fabric of the modern world, and the way we perceive ourselves.

The preceding ruminations also highlight an intriguing tension between metaphors as provisory hypotheses and as constitutive images. Although certain models can be explicitly established as such (as throw-away conceptual structures useful exclusively in terms of their predictive and explanatory value) the history of science repeatedly shows us that there is another important type of metaphor: a *metaphoricity* that is constitutive of thought itself, essential to the very possibility of science. On one hand, science wants to conceive of its rhetorical and representational apparatus as the *techne* of reason, an instrumental means to a higher end: knowledge, correspondence, truth. Yet metaphor can be conceived as the very condition of possibility of thought – suggesting the prospect that all *logos*, in the end, amounts to nothing but *techne*.

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[117] Gabbey A., "The Mechanical Philosophy and its Problems: Mechanical Explanations, Impenetrability, and Perpetual Motion", Pitt J.C. (ed.), *Change and Progress in Modern Science* (Dordrecht: 1985), 13.

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DESCARTES AS BRICOLEUR

Claus Zittel

I.

Can hot water freeze faster than cold water? In 1963 Ernesto Mpemba, a pupil from Tanzania, made an astonishing discovery while fabricating ice-cream at school: he found out that he could achieve his goal in a better time when he put either hot milk in the ice-box or previously heated milk that had cooled down. Therefore, when confronted with Newton's law of cooling by his physics teacher, he persisted in contradicting him and was laughed at by his class mates: he was doing "Mpemba-physics", they sneered. Mpemba, however, continued his experiments quite unmoved and even observed that his method was a common practice with the ice-cream makers of his town. The matter eventually reached a member of the school board, who repeated the experiments successfully and, together with Mpemba, published the results in an article.[1] The phenomenon has ever since been accepted and is known as the 'Mpemba-effect'.[2] What Ernesto Mpemba could

[1] Mpemba E.B. – Osborne D.C., "Cool?", *Physics Education* 4 (1969) 172–175.

[2] Cf. the article by Jeng M. (1998), "Can hot water freeze faster than cold water?", http://math.ucr.edu/home/baez/physics/General/hot_water.html and "Hot water can freeze faster than cold?!?" (2005), http://arxiv.org/PS_cache/physics/pdf/0512/0512262.pdf (with indications as to secondary bibliographical references), as well as Auerbach D., "Supercooling and the Mpemba effect: When hot water freezes quicker than cold", *American Journal of Physics* (1995) 63, 10, 882–885. It must be noted that Descartes did precisely not chose the most contra-intuitive case, which is that hot water freezes faster, but made his experiments with water that had cooled down again. Nevertheless, he could have covered and explained this effect with his theory, since he assumes that the particles of water have undergone a transformation in consequence of the heating. Modern explanations principally take the same direction as Descartes', cf. Chaplin M., "Water Structure and Behavior", http://www.lsbu.ac.uk/water/explan4.html#mpemba. As regards the appreciation and observation of the Mpemba-effect in history of science, the research on Descartes supplies us, as far as I can see, with no studies whatsoever. With the exception of the above-mentioned reference in Thomas Kuhn's text, there is only a very scant discussion by letter between Gallear and Deeson as to whether this effect was part of general knowledge in the 17. century: See: Gallear R., "The Bacon-Descartes-Mpemba phenomenon", *Physics Education* 9 (1974), 490 and Deeson E., "Bacon-Descartes-Mpemba", *Phys. Educ.* 10 (1975) 124–125. On the

not know: The phenomenon had already been observed by Aristotle, and later Francis Bacon.[3] But it is Descartes who has furnished us with the most detailed account of the experiment in his text *Les Météores* (AT VI 238) and in his letters. In a letter to Mersenne dated 1. March 1638, for instance, he writes:

> I wonder at your mentioning your purpose to point out the mistakes you will find in my book with regard to my experiments; for I will venture to assure you that there is nothing wrong in any of them, as I have carried them out myself, particularly the one where you can observe that *warm* water freezes sooner than *cold* one. I have not spoken of *warm* and *cold* water, but have stated that *water that has been held over a fire for a long time freezes sooner than other water.* For to rightfully carry out this experiment, the water has to cool down after boiling, until it has reached the same temperature as that from a well. Then one has to take water from this well and fill both waters into identical jars. There are, however, few people able to carry out experiments correctly, and when they are wrongly done, one often finds the exact opposite of what one ought to find.[4]

Descartes was right with his contra-intuitive example: It is possible that, under the same conditions, even water of 90°C freezes faster than water of 18°C. Science later regarded the descriptions of this phenomenon as incompatible with Newton's law of cooling and for a long time dismissed them as mere myth. They were eventually rehabilitated – significantly enough from outside the *scientific community*. This is an excellent example of how the formulation of a natural law can determine empirical perception and discredit a certain type of observation. Descartes' physics were in many fields "Mpemba-physics", and the text quoted above is quite representative of his methods of research: All his life Descartes observed and experimented, without hastily formulating principles.

This, however, is neither consistent with the usual image of Descartes, nor with the customary representations of the history of science, according to which the turn to empiricism and to the experiment in Baconian

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other hand, Scott's judgement of Descartes' Mpemba-experiment is remarkable for its ignorance: 'This statement, which the simplest of experiments could have refuted, was repeated with elaborate details in a letter to Mersenne, and it emphasises Descartes' readiness to rely on *a priori* conclusions.' Scott J.F., *The scientific work of René Descartes (1596–1650)* (London: 1976) 67.

[3] Aristoteles, *Meteorology* 348 b32; Francis Bacon, *Novum Organum* (1620), in Spedding J. – Ellis R.L. – Heath D.D. (eds.), *The Works of Francis Bacon* (New York: 1869) vol. VIII, 179–203, 235, 337 (this example Thomas Kuhn would likewise not miss, in: *Die Struktur wissenschaftlicher Revolutionen* (Frankfurt am Main: 1991) 31.

[4] AT II 29.

style had taken place primarily in England with the foundation of the *Royal Society*.[5] In these accounts, Descartes is depicted as the great antipode to Bacon. Descartes, especially, was considered to be responsible for the division between empirically grounded philosophy, on the one hand, and rationalistic deduction from first principles, on the other.[6] A closer look at Descartes' research practice, however, reveals this picture as dramatically simplified. In many fields of his natural philosophy, Descartes was above all an empirical researcher. There was generally a great deal of experimenting done in Europe – the far-reaching net of correspondence of Mersenne and the Baconian Nicolas de Peiresc ensured the exchange of the records of experiments or experiences.[7] The numerous compendiums in the English language which trace the principal lines of development of empirical philosophy from Bacon to Locke[8] are in great need of revision: The scientific practice of humanism and of so-called rationalism deserve greater consideration, and the exclusion of large parts of Europe, as well as the unilateral orientation of the mathematical-physical sciences, must be rectified. Also, the number of disciplines that could, in the Early Modern Period, be subsumed under 'Technology', 'Experimental Philosophy' or 'Scientific Practises', is more varied than often acknowledged. Would, for instance, the research on meteors in the Early Modern Period eventually be taken into account in historical evaluations, it would mandate a substantial

[5] See Shapin St. – Schaffer S., *Leviathan and the Air-Pump. Hobbes, Boyle, and the experimental life* (Princeton, NJ: 1985) and the critical reflection by Zittel C., "Konstruktionsprobleme des Sozialkonstruktivismus", in Zittel C. (ed.), *Wissen und soziale Konstruktion* (Berlin: 2002) 87–108.

[6] Critically: Engfer H.-J., *Empirismus versus Rationalismus? Kritik eines philosophie-historischen Schemas* (Paderborn: 1996). Perler D., "Was ist ein frühneuzeitlicher philosophischer Text? Kritische Überlegungen zum Rationalismus/Empirismus-Schema", in Puff H. – Wild Ch. (eds.), *Zwischen den Disziplinen? Perspektiven der Frühneuzeitforschung* (Göttingen: 2003) 55–80. Lüthy C., "What to Do with Seventeenth-Century Natural Philosophy? A Taxonomic Problem", *Perspectives on Science*, in 8 (2000) 164–195.

[7] For the experimental discourse by Pereisc see: Miller P.N., *Peiresc's Europe: Learning and Virtue in the Seventeenth Century* (New Haven: 2000) and "Peiresc and the First Natural History of the Mediterrean", in Mulsow M. – Assmann J. (eds.), *Sintflut und Gedächtnis* (München: 2006) 167–198. For a discussion of the crucial role played by observation and witnessing among humanists: Taussig S., "L'éruption du Vésuve de 1631: Naudé et Gassendi", ed. D. Bertrand, *Mémoire du volcan et modernité* (Paris: 2004) 345–368. Taussig S., "Les libertins erudits au pied du volcan: l' eruption du Vesuve de 1631", *Intellectual News* 14. Taussig S., "Introduction" to Pierre Gassendi, *Vie et moeurs d' Épicure*, ed. and transl. by S. Taussig, vol. 1 (Paris: 2006) VII–CXIV.

[8] See for instance: Garber D. – Ayers M. (eds.), *The Cambridge History of Seventeenth-Century Philosophy* (Cambridge-New York: 1998).

revision of the entire image of the currently accepted processes of formation of the Modern Period. For the characteristic scientific features of the age, consisting of the principal concepts of historiography such as the 'Copernican Revolution', 'mechanistic explanation of the world', 'the world as clock or machine' or 'mathematical method', and the corresponding set of images, are drawn initially from astronomically calculable phenomena and then extended to the entire sublunary sphere. The image of this sphere is thereby grossly deformed, as it is inevitably charged with the notion of calculable regularity and machine-like order. The sublunary sphere is, however, for the most part chaotic, dynamic and incalculable. To explore it experimentally was the aim of many natural philosophers – among them Descartes.

II.

While it cannot be said that the research on Descartes has neglected the topic of experience in his philosophy, it is striking that scholars in most cases only quote what Descartes wrote on experience and do not look at how he figured out experiments, worked them out and performed them in a concrete way in his scientific practice, and how he communicated about them. Hence, it was discussed again and again by Blake, Gewirtz, Gäbe, Engfer, Clarke or Garber:[9] Did Descartes, departing from evident basic principles, mathematically-fundamentally deduce the explanations of natural phenomena, questioning experience only as to what natural law was applied in the case in question? Or must he rather be regarded as a practical researcher of nature, proceeding inductively, assigning hypothetical status to his theories and thus even positioning himself somewhere in the methodological proximity of

[9] Blake R., "The Role of Experience in Descartes' Theory of Method", *The Philosophical Review* 38,2 (1929) 125–143. Gewirtz A., "Experience and the Non-Mathematical in the Cartesian Method", *Journal of the History of Ideas*, 2 (1941) 183–210. Gäbe L., *Descartes' Selbstkritik: Untersuchungen zur Philosophie des jungen Descartes* (Hamburg: 1972). Larmore Ch., "Descartes' Empirical Epistemology", Graukroger, S. (ed.), *Descartes: Mathematics, Physics, and Philosophy* (London: 1980), 6–22. Williams B., *Descartes, the project of pure enquiry* (London: 1978). Clarke D., *Descartes' philosophy of science* (Manchester: 1982). Engfer H.-J., *Empirismus versus Rationalismus? Kritik eines philosophie-historischen Schemas* (Paderborn: 1996). Petrus K. – Freudiger J., "Empirisches bei Descartes", *Studia Philosophica*, 55 (1996) 31–52. Gaukroger S., *Descartes' system of natural philosophy* (Cambridge-New York: 2002). Garber D., *Descartes embodied: Reading Cartesian philosophy through Cartesian science* (Cambridge-New York: 2001).

Bacon. The arguments on both sides have frequently been exchanged, and the ever-recurring text passages supporting sometimes the one, sometimes the other interpretation have been quoted often enough. But the fact that it is always the same passages that the debates in this context focus on, suggests that Descartes himself was not particularly interested in theoretic discussions about the significance of experience to his work.

Doubtlessly, the chief part of Descartes' scientific activities consisted in collecting and exchanging 'experiences'. Beck has therefore rightly concluded: 'Of all great philosophers, none, with the exception, perhaps, of Aristotle, devoted more time to experimental observation than Descartes.'[10] Throughout his life, Descartes never tired in his pursuit of 'experiences'. This meant not only that he himself incessantly made his own experiments, but that he also constantly attempted to elicit the results of research from other natural scientists. His letters to colleagues are exemplary in the politics of knowledge, perfecting the strategy and tactic of acquiring knowledge and of systematically spreading (or withholding) the data gained by observation or the results of experiments. When dealing with information, Descartes rose to the pinnacles of the art of rhetoric. If in his letter he nevertheless occasionally permitted himself to raise other questions, touching, for instance, on moral philosophy, he excuses this sort of idle amusement significantly by stating that in the meantime experiences were growing in his garden. In a letter to Chanut, written in his later years, he writes:

> That while I am waiting for the plants to grow in my garden which I need for some experiments [experiences] to continue my physics, I am spending some time also in thinking about particular problems in ethics [...].[11]

In what sense does Descartes here talk of 'experiences'? And what correlation is there between such experiences and his method? It is known – Desmond Clarke has, among others, pointed it out – that although the habitual language use at the time would have permitted it, Descartes made no distinction between experiment and experience and invariably termed observations, experiments and experiences as 'experiènces'. The Latin term 'experimentum', too, Clarke states, 'does not have any special connotation of a scientific experiment in his

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[10] Beck L.J., *The method of Descartes. A study of the regulae* (Oxford: 1952) 239.
[11] Letter to Chanut of 15. 6. 1646, AT IV 442.

vocabulary.'[12] Modern translations clarify this use of language according to its assumed meaning in different contexts. Here, however, we risk losing the clues about what Descartes might have regarded as the common point in all 'experiences'. We might rather ask: Did it make sense to Descartes not to make a distinction?

In order to answer this question one has to inquire into Descartes' precise way of 'collecting experiences'. Up to now this has mostly been done very selectively, focussed on what we nowadays call experimenting; even within this somewhat narrow range, the research has concentrated on selected examples from the field of optics: The attempts of cooperation with Ferrier in order to construct instruments have been the object of a study by Shea, and, more recently, by Burnett and Dupré;[13] the prism experiments to explain the rainbow and Descartes' use of the Camera obscura. Outside this field, above all, the barometer experiments of his later career attracted attention.

It will not be possible for me to present all the various forms and types of experiments and observations that Descartes, as a natural scientist, carried out in the fields currently known as physiology, psychology, anatomy, embryology, chemistry, physics, meteorology, astronomy, music, geology and mechanics. I will, however, attempt to expound some predominant characteristics, in order to determine what we might consider a specifically Cartesian style of experiment. I use the terms 'style of experiment' or 'experimental philosophy', interchangeably in order to compensate for the reduction which the modern term 'experience' implies and in order to interconnect the notions of 'experiment', 'observation' and 'experience'. With 'Experimental Philosophy' I therefore mean more – not only, how Descartes carried out experiments in a modern understanding, but also how experimenting in the sense of trial and error becomes a basic methodological feature of his work, this, in turn, suggests no systematic necessity to distinguish between passive observation and active experimenting.

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[12] Clarke D., *Descartes' Philosophy of Science* (Manchester: 1982) 19–24.

[13] Dupré S., "Newton's Telescope in Print. The Role of Images in the Reception of Newton's Instrument" (http://sarton.ugent.be/publications/preprints). Shea W.R., *The magic of numbers and motion: The scientific career of René Descartes* (Canton: 1991). Shea W.R., "Descartes and the French artisan Jean Ferrier", *Annali dell' IMSS di Firenze*, Anno VII, fasc. 2 (1982) 145–160. Burnett D.G., *Descartes and the Hyperbolic Quest: Lens Making Machines and their Significance in the Seventeenth Century* (Philadelphia: 2005). Gauvin J.-Fr., Artisans, Machines, and Descartes's Organon, *History of Science* vol. 44, 2, no. 144 (2006) 187–216.

III.

'According as henceforward I shall have the means of making more or fewer experiments', Descartes declares in his *Discours de la Méthode*, 'I shall in the same proportion make greater or less progress in the knowledge of nature.'

To increase his knowledge of nature, Descartes has to confront his method with practice – the explanations of natural phenomena can not be deduced in theory from evident principles, but have to be cumbrously worked out, one by one, by practical research. Descartes sneers at those who do not abide by these principles:

> [Many] […] often treat the most complex questions so unorderly […] as if they were trying to leap from the ground floor of a building onto the roof […] Amongst them those philosophers who, neglecting experience, think that truth will spring from their brains, like Pallas from the brain of Zeus.[14]

This is the reason why Descartes adds three essays to the *Discours de la Méthode* – experiments that are to exemplify his method – publishing the whole in a volume with the title: *Discours de la Méthode pour bien conduire sa raison et chercher la vérité dans les sciences. Plus la dioptrique, les météores et la géométrie*, qui sont des essais de cette *méthode* (Leiden 1637).[15] Not only does Descartes thus assign an experimental status to the *Essais*; in a letter he, moreover, explicitly places the entire *Discours* under the primacy of practice:

> I have not put Treatise on the Method (Traité), but Discourse on the method, which means Preface or Conversation on the Method (Préface où Advis de la Méthode), in order to show that I do not intend to teach the method, but only to discuss it. As can be seen from what I say, it is more concerned with practice than with theory. I call the following

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[14] Rule 5, AT X 380.

[15] AT VI. The English translation of the *Météores* is quoted from: René Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, ed. P. Olscamp (Indianapolis: 2001). As even the title proves, Olscamp takes some liberties in the order of the essays and the translation, but more particularly in the text, by using his own drawings instead of Descartes' without indicating these changes. The only English edition of the essays is therefore useless. Editions with the original pictures are: René Descartes, *Opere scientifiche* (a cura di Ettore Lojacono) (Turin: 1982); René Descartes, *Discours de la Méthode, plus la Dioptrique, les Météores et la Geometrie*, ed. M. Serres (Paris: 1987); Descartes; *Les Météores/Die Meteore*, ed. C. Zittel (Frankfurt am Main: 2006).

> treatises Essays in this Method (Essais de cette Méthode), because I claim that what they contain could never have been discovered without it.[16]

As can be seen, the Essay on the Meteors was not published separately, but within a collection of essays for which the *Discours de la Méthode* served as introduction. The majority of the philosophic interpretations of Descartes' works are, however, primarily based on the *Meditationes* and the *Discourse on Method*, which, taken together, constitute less than five percent of his oeuvre. In most cases, his writings on natural philosophy are read only selectively from the point of view of each reader's profession, or are, as in the case of his essay on the Meteors, with surprising stringency almost entirely overlooked in science. The absurd consequence is that an introduction was received, but the various works by which the method explained therein was to be demonstrated in application, were either totally ignored or regarded only separately in other contexts. Editorially, too, the *Discourse on Method* was detached from the essays early on, which is both a cause and a symptom for the distortions in the reception of Descartes' writings. For Descartes' *Discourse on Method* is, even beyond the realm of philosophy, the most famous philosophical text of the Early Modern Period; it is commonly considered to be the *one* manifesto of the foundation of Early Modern rationalism, a philosophy distrusting the perception of the senses and accepting reason alone as the certain source of perception. Once reason had clearly and obviously recognised basic truths, all other questions might be answered through deduction, which means that natural phenomena, too, can be explained deductively. By his 'deductive-mathematical' method – in other words: by the mathematical ideal of certainty thus becoming the criterion for the explanation of nature.[17] Descartes is said to have become founder and precursor of the modern scientific way of thinking.

On the other hand, Descartes is accused of being responsible for a 'loss of reality' in philosophy by positing the absolute authority of the rational concept of perception. By the depreciation and fragmentation of the perception of the senses he has, according to this view, permanently discredited visualisation as mode of perception.[18] However, a

[16] Letter to Mersenne dated March 1637, AT I 349.

[17] See for instance: Skirbekk G. – Gilje N., *Geschichte der Philosophie*, vol. 1 (Frankfurt am Main: 1993) 317 f.

[18] A prominent representative of this opinion is Michel Foucault: 'In the uniform light of his barred senses, Descartes has broken with every possible fascination, and

comparison of the supposedly mathematic-deductive ideal of method in the *Discourse on Method*, on the one hand, and the essays, on the other, reveals a great disparity between this ideal and many of the fanciful applications of the allegedly reductionist method. This is particularly true for the essay on the meteors, since the meteors traditionally appear as incalculable renegades in the otherwise well-ordered realm of natural philosophy and are generally not easy to grasp by theory.[19]

What, therefore, is meant by a practical focus of the method? In another letter Descartes specifies his aim:

> To this purpose I lay out the general method, which, in truth I do not teach; but I will try to give samples of it in the following three treatises, which I unite with the discourse in which the method is dealt with. For the first treatise I choose a subject with features from both philosophy and mathematics [*Dioptrics*], for a second a purely philosophical one [the *Meteorology*] and for the third a purely mathematical one [*Geometry*].[20]

Why is it to the *Meteorology* of all texts, to an essay almost completely ignored in history of philosophy, that Descartes assigns a purely philosophic subject, and what does he mean by it? Repeatedly, in this context, he refers to Bacon. For example, in a letter to Mersenne in 1630, he writes:

> [...] that you wish to know a means of making useful experiences. As to that I have nothing to say, after what Verulam has written concerning it, except that, without being too curious in searching all the little details concerning a matter, it would be necessary chiefly to make general collections of all the most common things, such as are most certain, and can be known without expense. As that in all shells the spirals turn in the same direction, and to know whether it is the same on the other side of the equator.[21]

As the first practical example of his *Instauratio Magna*, Bacon had, in 1622, published no other than his *Historia Ventorum [History of Winds of the first Title in the Natural and Experimental History, for the foundation of Philosophy which is the third part of the Instauratio Magna]*. The natural

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when he sees, he is sure of what he sees.' Foucault, M., *Wahnsinn und Gesellschaft* (Frankfurt am Main: 1973) 247. Compare Scheer B., *Einführung in die philosophische Ästhetik* (Darmstadt: 1997) 38–46.

[19] For details see my introduction to: Descartes, *Les Météores/Die Meteore*.

[20] AT I 370.

[21] To Mersenne, 23.12.1630, AT I 195–196.

history of the winds is an interesting text for the history of empirical science, insofar as in it readers are directly invited to collect accounts, not by scholars, but by practical men, in this case, sailors. This text is a collection of all sorts of observations which it presents without any apparent order, placing mythologems alongside Aristotelian explanations or simple descriptions. All entries are very short – there are no detailed descriptions of experiments. Whereas Bacon focuses his attention on specifically those cases diverging from the average and from which he hopes to gain new insights (to that purpose he collects as many and as heterogeneous cases as possible), Descartes' first aim is to record what can be known with certainty, in order to proceed systematically from this secured basis. Consequently, he begins by collecting simple cases. Like Bacon, however, Descartes demands that first as much data as possible be compiled and that this be made the aim of collective efforts. He writes to Mersenne:

> You tell me that you have Scheiner's description of the phenomenon at Rome. If it is more detailed than the one which you sent me before, I shall be most obliged if you will take the trouble to send me a copy. If you know any other author who has made a special collection of the various accounts of comets, I shall be very obliged if you will inform me of it. For the last two or three months I have been quite caught up in the heavens [...]. You once told me that you knew some people who were so dedicated to the advancement of science that they were willing to make every kind of experiment at their own expense. It would be very useful if some such person were to write the history of celestial phenomena in accordance with the Baconian method and to describe the present appearances of the heavens without any explanations or hypotheses [...] such a work would be more generally useful than might seem possible at first sight and it would relieve me of a great deal of trouble.[22]

In the *Discours de la Méthode*, Descartes likewise repeatedly demands the institution of collective research programs with a utilitarian aim according to Baconian principles:

> Moreover I have reached a stage at which, it seems to me, I can see well enough how I should do most of the experiments that used for this purpose. But I also see that they are such and are so numerous that neither my personal effort nor my financial resources – even if I had a thousand times more than I actually have – would ever be enough for all of them.

[22] To Mersenne, 10 May 1632. AT I 251.

> Thus in future I would advance more or less in my knowledge of nature in proportion to my capacity to do more or fewer experiments.[23]

Descartes believed that he could not keep principles

> hidden without sinning greatly against the law that obliges us to realize, as much as we can, the general welfare of all people. For they made me see that it is possible to achieve knowledge which would be very for life; and that, in place of the speculative philosophy that is taught in the Schools, it is possible to find a practical philosophy by which, knowing the force and actions of fire, water, air the stars, the heavens, and all the other bodies that surround us, as distinctly as we know the various crafts of our artisans, we would be able to use them in the same way for all the applications for which they are appropriate, and thereby make ourselves, as it were, the lords and masters of nature.[24]

This leads him to the Baconian project

> to communicate truthfully to the public what little I had found, and to encourage good minds to try to make further progress by contributing – each according to their inclination and ability – to the experiments that would have done, and also by communicating to the public all the things they learn. Thus, if later people begin at the point that their predecessors had reached and thereby join together the lives and labours of many, we would make much more progress together than each person could ever make on their own.[25]

IV.

The only text in which Descartes gives a detailed account of his experimental research of these years to the public, is *Les Météores*. In this essay, Descartes presents the first comprehensive scientific attempt of the Early Modern Period to explain the structure of the earth and all the meteors. It is here for the first time that he publicly canvasses his theory of matter. Unlike his procedure in the *Dioptrique*, he does not address the text to artisans, but to a more general public with natural philosophical knowledge. He could rightly claim the merit of having first found plausible hypotheses to explain numerous hitherto

[23] Descartes, *Discourse on Method and related writings*, translated with an introduction by D.M. Clarke (London: 1999), 46.
[24] Ibid., 44 (AT VI 62).
[25] Ibid., 45 (AT VI 63).

enigmatic phenomena. Contemporaries, by all means, valued Descartes' text; it therefore constitutes an indispensable source for those wishing to understand how weather phenomena were scientifically explained in the 17th century.

Descartes' essay on the meteors constitutes a radical break with the Aristotelian paradigm of the explanation of celestial phenomena. Aristotle referred to special substantial qualities of each celestial body in question to explain its changes and effects. Descartes replaces this type of explanation by a mechanistic theory, according to which all phenomena can only be explained on the *hypothetical* basis of the form and movement of certain types of particles of matter. But how, starting from this point, is it possible to grasp the whole genesis and chaotic variety of terrestrial phenomena in a consistent model? The formation of winds, clouds, ball-lightening, colours or snow crystals can clearly not be deduced in a mathematical or logical sense. Since the meteors govern the entire sphere of phenomena observable on earth, Descartes' physics deal in most cases not with mathematically or logically deductible phenomena, but with such apparitions and their effects demanding observation, experienced examination and exact description. Accordingly, Descartes argues, it is not reason that judges celestial apparitions with certainty: our eyes 'are the most certain judges that we can have for knowing the force of light'.[26]

Since Descartes obviously did not deduce natural phenomena from basic premises in his *Meteorology*, what *did* he do? Collection, exact description and comparison of simple experiences are the first steps; the phenomena are then to be explained on this basis, and yield an explanation which is not purely theoretical, but has to prove its explicative power in practice. Descartes proposes to begin with simple and certain observations. This clearly recalls the methodical rules he had worked out in the *Regulae* and in the *Discourse on Method* after the model of geometry. There, he speaks of certain insights, of intuitions which, in turn, form the basis of further intuitions. Descartes' explanation of the transition from one intuition to the next, however, remains rather vague. The way he treats the simple observations gives the impression that he wanted to shift this process from inside the head to the outside in his scientific practice, choosing certain observations instead of inner

[26] Descartes, *Meteorology* 295, AT VI 277.

insights as point of departure. In order to pursue this supposition, we should bear in mind the second and third rule:

> To subdivide each of the problems that I was about to examine into as many parts as would be possible and necessary to resolve them better. The third was to guide my thoughts in an orderly way by beginning with the objects that are the simplest and easiest to know and to rise gradually, as if by steps, to knowledge of the most complex, and even by assuming an order among objects in cases where there is no natural order among them. And the final rule was: in all cases, to make such comprehensive enumerations and such general reviews that I was certain not to omit anything.[27]

The splitting of a problem into its most simple components and the successive answering of questions ascending from the easiest to the most complex is nothing but mental training, as long as it is merely considered as a theoretical process. This changes, however, when the process is also understood as a set of instructions for the concrete or hypothetic dissection and assemblage of objects and apparitions in nature for explanatory purposes. This means that it is no longer applied to trains of thought, but to real and imagined correlations in nature. If one wants to understand how a clock works, one has to take it to pieces and then put it together again in the right order. Not only such apparatuses, however, but every natural phenomenon can be split into its components and then shown to be a special constellation of these parts.

What materials compose an object and what characteristics the object has as a result of its composition can not be discerned beforehand; every object in question must be taken to pieces and its dispositions, forms and special features studied. Once the individual elements have been described, one can proceed to 'deduce' the natural phenomenon. In this context, a deduction is not a logical conclusion, although Descartes explicitly qualifies it as mathematical or mechanistic. Should one, for instance, wish to deduce the qualities of the winds in a strict sense, one would, according to Descartes, first have to explain the 'entire structure of the universe' (270), a thing he, however, had no intention of doing. We rather find the analysis of simple observations, the dissection of simple phenomenon and their actual or theoretical reassemblage; then, when this procedure has succeeded, it becomes the

[27] Descartes, *Discourse on Method*, 16 (AT VI 20).

model for similar but more complex formations. This is what Descartes means, for example, when he declares himself able to deduce an entire human being from the mere mass of semen. Depending on the object, this *bricolage* is more or less difficult to realise: some objects are out of reach, being high up in the sky or too small to be perceived because they have no bodily existence, as, for instance, reflections of light; in other cases the consistency of the objects makes such a de-construction difficult and requires the use of instruments – this is true for air and water, for instance. Descartes' research on nature can almost entirely be regarded as a permanent attempt to tinker about with simple forms until a phenomenon is explained from its composition. Descartes has a name for this procedure, which he opposes to abstract geometry: he terms the dissection of objects in elementary forms and the combining of those elements 'concrete geometry' – a method he regards as purely philosophical and not mathematical.

> But I have only decided to give up abstract geometry, which is to say to inquire into questions that serve only as a mental training; my decision is prompted by the wish to have more leisure to practice another form of geometry, dedicated more to questions concerning the explanation of natural phenomena. If he finds pleasure in reading what I have written about the salt, the snow and the rainbow etc., he will find that my entire physics are nothing but geometry.[28]

V.

The decisive impulse for Descartes to turn his back on abstract geometry came in the guise of a scientific challenge. On 20 March 1629, the Jesuit astronomer Christoph Scheiner observed a rare apparition in the sky over Frascati near Rome: the apparition of several suns. This phenomenon was as spectacular as it was difficult to explain. Scheiner's fast-spreading report about the so-called parhelia or mock suns also reached Descartes, whose interest and scientific ambition were roused by the news. He abandoned all his prior occupations and started to collect data and experiment. A mere two months later he wrote to Mersenne:

[28] Letter to Mersenne of 27. 7. 1638, AT II 268.

> Before I could give him my answer I had to interrupt my current work in order to make a systematic study of the whole meteorology. But I think I can now give some explanation of the phenomenon. I have decided to write a little treatise on the topic; this will give the explanation of the colours of the rainbow (a topic which has given more trouble than other) and for all sublunary phenomena in general.[29]

What had, in the beginning, been nothing more than a preoccupation with a minor matter rapidly developed into a huge long-term research project. Only few days after he had begun with his studies, Descartes announced to Mersenne: 'Rather than explaining just one phenomenon I have decided to explain all the phenomena of nature, that is to say, the whole of physics.'[30]

Descartes devoted the following years to experiments, observations and the collection of accounts – data that was later integrated into *Le Monde*, the *Dioptrique* and the *Meteorology*. His research was open and tentative, not at all like the wide-spread image[31] of the philosopher confidently commanding nature to his liking. Descartes always remained dependent on his scientific contacts, his financial means and fortuitous external circumstances. He admitted difficulties with the implementation of more complex experiments[32] in the tradition of Bacon, that create facts only by the manipulation of nature; he therefore declared his increasing preference for observations for which neither apparatuses

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[29] Letter to Mersenne of 8. 10. 1629, AT I 23.

[30] Letter to Mersenne of 13. 11. 1629, AT I 70.

[31] See Scott J.F., *The scientific work of René Descartes* (1596–1650) (London: 1976) 65 on Descartes' *Meteorology*: 'Much of it is far too speculative. Its chief blemish lies in Descartes' failure to recognise the decisive nature of even the simplest experiment.'

[32] For this reason Descartes attempted to cooperate with the constructors of instruments, a project that had but little success. But even for simpler observations, of which a huge number could be made, Descartes depended on cooperation. Fantastic as some of his speculations may appear today, a reliable empirical basis was nevertheless indispensably necessary to him. If he failed to procure the necessary information, Descartes was helpless in many fields of science; especially in the Dutch province he was scientifically more and more isolated. Thus he was risking serious scientific disgrace. Accordingly he reproached Mersenne for his increasing unwillingness to provide him with information: 'You ask me to write something on the experiments with mercury, and yet you neglect to inform me about them, as if I were to guess what they are. But I must not take the risk of doing that, for if I hit upon the truth, people might think that I had done the experiment here, and if I failed to do so, people would have a poorer opinion of me. But I shall be obliged to you if you would please give me a straightforward account of everything you have observed; [...] I am surprised that you have kept this experiment secret for four years, as has the afore mentioned M. Pascal, without ever reporting anything about it to me or telling me that you had begun this summer.' Letter to Mersenne of 13.12.1647, AT V 98–100.

nor money were necessary. He was pessimistic with regard to his own dexterity, admitting his preference for ready-made experiences falling from the sky:

> If from time to time, you have directed your eyes outside the cosiness of your warm chamber, you might have noticed other meteors in the air, than those about which I have written, and you will be able to give me useful instructions. A single observation I made in 1635 about the hexagonal snow, was reason for the treatise I wrote on it. If all experiences that I need for the rest of my physics, could likewise fall from the clouds and required nothing but my eyes to perceive them, I would be in hopes of procuring them in a brief space of time. But as one also wants hands to make the experiences, and I have no other than my own, I lose every inclination to proceed.[33]

Two years later – the *Meteorology* had already been published – he once again ranks himself amongst the 'few people able to carry out experiments correctly', and declares that 'when they are wrongly done, one often finds the exact opposite of what one ought to find.'[34]

VI.

But, what experiments did Descartes actually carry out? It is often difficult to ascertain whether Descartes indeed carried out or observed an experiment, or whether he only asserts to have done so. Nevertheless, some inferences can be made from the passages quoted so far: 1. Descartes lacked the money for expensive instruments. 2. He was, despite his assertion of having executed 'millions of experiments', very clumsy (the few existing drawings by his own hand are a shocking testimony of this). Thus, he was confronted with quite 'down-to-earth' problems that can serve as a basis for a preliminary typology of Descartes' experimental practice. There are:

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[33] AT IV, 377 f. Compare: 'I remarked, moreover, with respect to experiments, that they become always more necessary the more one is advanced in knowledge; for, at the commencement, it is better to make use only of what is spontaneously presented to our senses, and of which we cannot remain ignorant, provided we bestow on it any reflection, however slight, than to concern ourselves about more uncommon and recondite phenomena' (*Discourse on Method*, AT VI 63).

[34] Letter to Mersenne of 1. 3. 1638; AT II 29.

1. Simple observations, as by means of the shells above-mentioned, that he can make himself and for which additional information can be obtained for the sake of comparison.
2. Simple visual experiments: By walking to and fro, one discovers that, from a distance, a square tower appears round. Or experiments with the manipulation of one's own visual perception: Descartes describes, for instance, what happens when you press on your eye for an extended period of time, or how suddenly, at night, a corona appears around the flame of a candle. Here, it is not merely an observation, but also his self-observation that is communicated. One could further distinguish between observations that Descartes finds credible, because he can easily verify them himself and others that are credible but which Descartes cannot test though they are, in principle, verifiable, such as e.g. accounts given by sailors; there are also mysterious observations that could be verified but are not worth verification and, finally, improbable observations that are, however, reported by credible witnesses: these are, if necessary, explained by Descartes.[35]
3. Experiments that do not require much adroitness. The dissection of animal carcasses requires less dexterity than the use or even construction of instruments, and carcasses are cheaper to procure. Therefore, Descartes devoted himself extensively to anatomical studies. If, however, the objects of study are not dead animals, but rather the biological processes of transformation, construction plans and models are of no help. For those processes, Descartes turns to the observation of the development of chicken embryos, as well as to the abundantly illustrated book by Fabricius[36] and likewise studies

[35] For instance, he writes in a letter to Meysonnier of 29. 1. 1640, ibid. 182: 'As for the likenesses of little dogs, which are said to appear in the urine of those who have been bitten by mad dogs, I must admit that I have always thought it was a fable, and unless you tell me that you have seen very distinct and well-formed specimens I shall still find it difficult to believe in them. However, if it is true that they can be seen, they could be explained in some way similar to the birth marks which children receive from the cravings of their mothers.' AT III 20.

[36] 'And as for the formation of chicken in the egg, more than 15 years have passed since I have read what Fabricius da Aquapendente wrote about it, and I have myself, at times, opened eggs to see this experience (voir cette expérience). But my curiosity did not end here. I once had a cow killed which I knew had been pregnant for a short time, because I wanted to see her foetus. And when I was told, that the butchers in this country often kill pregnant cows, I had more than a dozen venters brought to me, in which were small calves, some of the size of mice, others as big as rats or small dogs.

processes of fermentation. He also permanently refers to everyday experiences and does not distinguish between scientific and non-scientific accounts of experiences.

4. Experiments with instruments, e.g. a prism, to explain the refraction of light and the colours of the rainbow in the *Meteorology*. This is one of the rare examples of experimenting in the modern sense. Based on these experiments – those most frequently cited by Descartes scholars – Descartes formulates the laws of refraction. The Rainbow explanation is considered Descartes' favourite epistemological model.[37] The last discourses of the *Meteorology*, amongst them the prism experiment, are, however, not in principle separated from the earlier ones, they merely focus on another, '*fictitious*' realm of objects (phenomena, that are based on mere optic effects and that can, therefore, not be practically dissected). It is this level that requires mathematical description. According to Descartes' definition, this is not a purely philosophical subject, but one mixed with mathematics. This experiment, too, is reported in the first person. Here, the traditional distinction between a solely individual experience and an impersonally

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Therewith I have been able to observe much more than with the chicken, because the organs are much larger and much better visible.' AT IV 555.

[37] Hence, the discourse on the rainbow is the only one from among the *Meteorology* which, as assumed model of the Cartesian method, called numerous interpreters into action. Vgl. z.B. Armogathe J.R., "The rainbow. A privileged epistemological model", in *Descartes' Natural Philosophy*, ed. Gaukroger St. – Schuster J. – Sutton J. (London: 2000) 249–257; Tiemersma D., "Methodological and theoretical aspects of Descartes' treatise on the rainbow", *Studies in the History and Philosophy of Science* 19 (1988) 347–364. Ribe N., "Cartesian optics and the mastery of nature", *Isis*, 88 (1997) 42–61; Garber D., *Descartes embodied*, 85–111; Scott, *The scientific work of René Descartes (1596–1650)* 71–83; Werrett S., "Wonders never cease: Descartes's Météores and the rainbow fountain", *The British journal for the history of science* 34, 129–147.

In this context researchers invariably quote Descartes' letter to Vatier of 22. 2. 1638 (AT I, 559), in which he praises his discourse on the rainbow as exemplary description of a natural phenomenon. There are, nevertheless, other letters with different views, in which Descartes likewise admits other discourses from the *Meteorology* as natural exemplification of the method (see above). Some partisans of the traditional line of interpretation support their view with the assumption that Descartes had, in the last three discourses in the *Meteorology*, returned to mathematics and had only then quitted the sphere of scholastics. Since the first seven discourses do completely without mathematics as method of examination and explanation, they have been classed, as a whole, within the scholastic tradition (Gilson E., "Météores cartésien et météores scolastiques", *Revue néoscolastique de philosophie* 22, 23, 358–84, 73–84, 124). The ideal of mathematics cherished by interpreters was obviously not shared by Descartes and leads to an artificial historical and systematic splitting of his work in modern and outdated parts. Descartes himself did certainly not separate the last discourses from the earlier ones – neither editorially nor methodically.

made, general experience which could alone claim scientific validity, can not be applied.

5. Apparatuses: Automata had already fascinated the young Descartes. He had seen many, for example in grottos and even though he was, naturally enough, not permitted to take them to pieces, he nevertheless had the opportunity to study their construction and mechanics in detail in the works of Johannes Faulhaber or Salomon de Caus.[38]
6. As for distillation experiments, he could carry out simple ones himself; the more complex, he either watched in alchemist laboratories,[39] or read about in the works of Della Porta and subsequently described them in the *Meteorology*.

On closer observation, this typology proves to be preliminary, because in most cases the different dimensions of experience in Descartes' works can not be separated, but are all invariably included into an interaction of scientific imagination, empirical observation and theoretic speculation, as I will explain further in the following section.

VII.

If one wishes to take single natural phenomena to pieces with the eyes and the hands, the explanatory *bricolage* soon reaches practical limits. At this point, Descartes introduces hypotheses about the shape the invisible micro-particles must have to be able to form certain combinations. The combining is now no longer performed on the grounds of observation, but by means of imaginary elementary forms. Accordingly it can be read in the very first discourse of the *Meteorology*:

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[38] Descartes had been working with optic effects as proofs of a *scientia mirabilis* since his youth. His notes *Cogitationes privatae*, known under the title of *Thaumantia Regis*, AT X 215–216 can be mentioned in this context. See: Baltrusaitis J., *Anamorphoses ou perspectives curieuses* (Paris: 1955); Massey L., "Anamorphosis through Descartes or Perspective Gone Away", *Renaissance Quarterly* 50, 4 (1997) 1148–1189; Zittel, "*Mirabilis scientiae fundamenta.* Die Philosophie des jungen Descartes (1619–1628), in Berns J.J. – Neuber W. (eds.), *Seelenmaschinen. Gattungstraditionen, Funktionen und Leistungsgrenzen der Mnemotechniken vom späten Mittelalter bis zum Beginn der Moderne* (Wien-Köln-Weimar: 2000), 309–362; Shea, *The magic of numbers and motion*.

[39] See for instance: 'those oils that alchemists usually extract from dried plants to the top of the beaker, when having steeped them in a great deal of water, they distil the whole together, and thus cause [...]' (Descartes, *Meteorology* 271, AT VI 241).

> I assume first, that water, earth, air, and all other such bodies that surround us are composed of many small particles of various shapes and sizes, which are never so well arranged, nor so exactly joined together, that there do not remain many spaces around them. And I assume that these spaces are not empty, but are filled with that very fine material [...].[40]

Those basic hypotheses, (still abstract at the beginning) Descartes then fills with life and it is only in this concrete visible form that they become elements in a chain of metaphors and pictorial comparisons by which the differences of particles, their forms of combination and their transition to different physical conditions are explained: water particles, for instance, are long and slippery like little eels, which is why they do not permanently interlace; particles of earth, on the other hand, being shaped like branches, get hooked together more firmly, thus composing hard bodies etc.:

> [...] Then, in particular, I assume that the small particles of which water is composed are long, smooth, and slippery like little eels, which are such that however they join and interlace, they are never thereby so knotted or hooked together that they cannot easily be separated;[41] [...] Thus you can picture the difference between water and ice as between group of small eels – either alive or dead – floating in a fishing boat full of holes through which water of a river flows, agitating the eels; and a group of these same eels, quite dry and rigid with cold on the shore;[42] [...] and on the other hand, I assume that nearly all particles of earth, as well as of air and most other bodies, have very irregular and rough shapes, so that they need be only slightly intertwined in order to become hooked and bound to each other, as are the various branches of bushes that grow together in a hedgerow. And when they are bound together in this way, they compose hard bodies like earth, wood, or other such things.[43]

From the hypothetically assumed morphology of the individual particles and their combinations alone, the whole construction and formation of nature is to be deduced by means of pictorial analogies. To this purpose Descartes imagines a gigantic panorama of various micro- and macro-physical formations and collisions of particles, which he describes in painstaking detail, visualising his cause with many illustrations and daring analogies and metaphors. The exactness and meticulousness of his observations and descriptions merit particular acknowledgement con-

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[40] Descartes, *Meteorology* 264, AT VI 233.
[41] Descartes, *Meteorology* 264, AT VI 233.
[42] Descartes, *Meteorology* 267, AT VI 235.
[43] Descartes, *Meteorology* 264, AT VI 233.

sidering the contrary clichés about Descartes prevalent amongst modern scholars. For example, Descartes is able to concentrate, for pages on end and with phenomenological precision, on nothing but the genesis of a grain of salt. He puts aside standard causal explanations in favour of chains of effects resulting from the incidental disposition of particles, which is to say from their shape and position. Descartes here applies no operational mode of combination in a lullistic or ramistic sense; his procedure merely implies the hypothetical supposition of random collisions of differently shaped particles, which, depending on their disposition, split, change their shape, move here and there, unite with others in this way or that. Even though Descartes explicitly operates with hypotheses of shape, and it generally is of no consequence to him what hypotheses one proposes as long as they are simple, he emphasises the fact that he did not think his hypotheses up arbitrarily, but established them on the grounds of an exact observation of nature. He suggests to the skeptical that they 'notice that we perceive such particles with the bare eye in a great many bodies: We can see, for instance, that there are small bodies in stones, veins in wood and [. . .] in meat.'[44]

The reference to appearances is a continuous motive throughout the text. *The Meteorology* is composed of discourses. True to their name, they are conversations with the reader. In them, it is always practice that triumphs. Almost all descriptions of experiments are in the first person, e.g.: 'I have seen or done this or that', or address the reader directly: 'You can bring this to your mind by a simple experiment.' Rhetorically, the *Discourse on Method* and the Essay on the Meteors, like the theatre, aim at seeing, speaking and listening; textuality as a decisive feature fades because the texts are perceived more as conversations than as written texts. The person addressed is encouraged to acquire knowledge by his own sensual perception. The text is full of such encouraging phrases – '*Watch, you will see, put your finger, [. . .] as you can perceive in the picture*.' In the *Discourse on method* Descartes asks his readers, for instance, to place the heart of a freshly butchered animal next to the book while perusing his descriptions, so as to enable them to follow his explanations with their own eyes and feel with their own fingers.[45] The person addressed

[44] Ibid., 421.

[45] Descartes, *Discourse on method*, 36 (AT VI 50). 'Finally, in order that those who are not familiar with the force of mathematical demonstrations and are unaccustomed to distinguishing true reasons from probable ones, may not be tempted to reject this without examination, I wish to advise them that this movement that I have just

ought not to remain passive, but should perceive the objects with as many senses as possible: This is learning by perception, knowledge through action.[46] Accordingly, Descartes makes extensive use of pictures in virtually all his writings. Depending on the context, this is done in very different ways, a fact that testifies to his sensitivity for the specific powers of illustrations.[47]

VIII.

In the first discourse of the *Meteors*, Descartes, as previously mentioned, introduces his theory of matter as a basic hypothesis. He subsequently discusses the exhalations (Discourse 2), the salt (3), the winds (4), clouds (5), snow, rain, hail (6), thunderstorm and lightening (7), rainbow (8), cercles and corona (9) and finally the parhelia (10).

In his text on meteors, Descartes keeps for the most part to the traditional order of the subjects, as was customary in the scholastic commentaries on Aristotle. In the beginning, however, he acts like the director of a theatre guiding an audience through the programme, announcing, for instance, that he will accompany the vapours through the air, make them thicken in different places or create a beautiful portrait of the rainbow.[48] It is not by chance that he talks of a portrait – metaphors drawn from painting can be found throughout the text. He often speaks of his descriptions of nature in terms of painting or drawing and thus suggests that the links between his observations and explanations and

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explained follows just as necessarily from the dispositions of the organs alone (which can be observed in the heart with the naked eye), from the heat (which one can feel there with one's fingers), and from the nature of the blood (that can be known by experience), as the motion of a clock follows from the force, arrangement and shape of its counterweights and wheels.'

[46] 'And to make it easier to understand what I shall say about it, I would like those who are not trained in anatomy to take the trouble before reading this to have cut open in front of them the heart of a large animal with lungs'. Descartes, *Discourse on Method* 34 (AT VI, 47).

[47] See Lüthy Chr., "Where Logical Necessity Becomes Visual Persuasion: Descartes' Clear and Distinct Illustrations", in Maclean I. – Kusukawa S. (eds.), *Transmitting Knowledge: Words, Images and Instruments in Early Modern Europe* (Oxford: 2005) 97–133; Zittel C., "Abbilden und Überzeugen bei Descartes", in K. Enenkel – Neuber W. (eds.), *Cognition and the Book. Intersections. Yearbook for Early Modern Studies* (Leiden-Boston: 2004) 535–601. Zittel C., *Theatrum philosophicum. Descartes und die Rolle ästhetischer Formen in der Wissenschaft* (Berlin: 2008/2009), forthcoming.

[48] Descartes, *Meteorology* 263–264 (AT VI 231–232).

his arrangements of them are not deduced in a strictly logical sense, but rather aesthetically. But what are we to make of this?

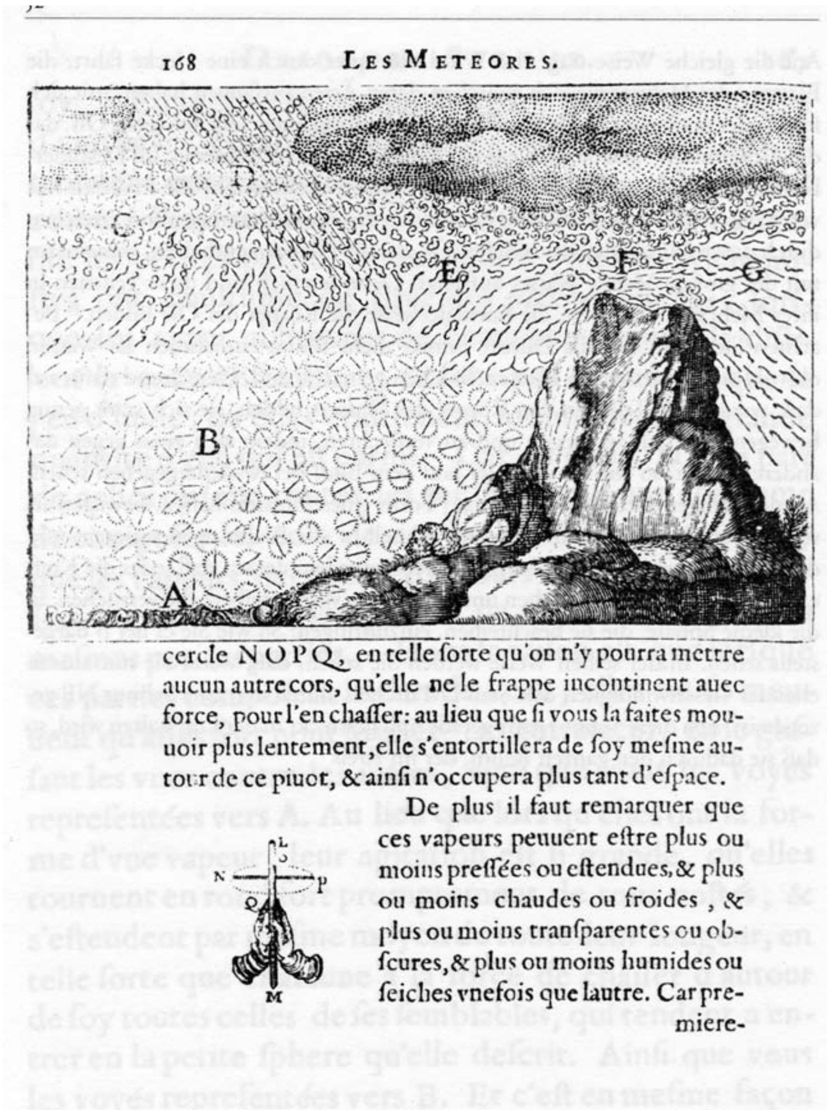
The morphological alphabet (Christoph Lüthy), which is introduced in discourse 1, I have already sketched; in discourse 2 Descartes applies it to explain the shape and behaviour of the particles of water, which he visualises with a first illustration:[49]

The picture is mimetic as well as abstract – the traditional distinction of scientific pictures into diagrammatical or realistic depictions is of little use here. One can see a realistic formation of rocks, a cloud in the upper right corner, otherwise strange lines and dotted circles. The picture shows how the longish particles of water move differently in different situations in space. At A, the particles are in such movement that they bend and interlace, thus forming the body of the water. At B, they have room to move and rotate with great velocity; here, they have taken on the form of vapour. At D, the fine particles of matter are moving at a slowed down pace and thus lose their long-stretched shape. The particles likewise lose speed at E, where they are stuck beneath a cloud and cannot properly expand. The dotted outline of the circle is not the innate form of the particles, but results from their movement. The rotation depicted at B, for instance, is explained by Descartes by means of an experiment the reader is encouraged to carry out himself: If we turn a pivot, through which a cord is passed, very fast, 'the cord will describe a circle, striking with force every body that comes in its way, in order to drive it out.' If, however, the cord is moved with less vigour, 'it will wrap itself around the pivot, and thus will not occupy so much space.'[50] Moreover, 'the vapours represented at B, E, and F are transparent[51] and cannot be distinguished from the rest of the air by

[49] Since in Descartes' works explanatory comments on the pictures by the editors and the indication of the sources are mostly either missing altogether or remain vague, the reader can hardly ascertain how closely Descartes cooperated with the artists. It is known, however, that he designed the illustrations for the essays and the *Principia* together with Frans van Schooten. Before the *Discours de la Méthode* and the *Essais* where published, he also thoroughly consulted Constantin Huygens on all details of the design of the book, discussing the character style, the margins, the design of the paragraphs and even the quality of the paper. (Cf. the letters to and from Constantin Huygens, AT II, 653–708). A Renaissance-edition of Machiavellis *Il Principe* served as a model in questions of typographic design, cf.: Jean-Pierre Cavaillé, "Descartes stratège de la destination", *XVII^{e} siècle* 177 (1992) 551–559.

[50] Descartes, *Meteorology* 271 (AT VI 242).

[51] See Descartes, *Meteorology* 273 (AT VI 245).



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cercle N O P Q, en telle ſorte qu'on n'y pourra mettre aucun autre cors, qu'elle ne le frappe incontinent auec force, pour l'en chaſſer: au lieu que ſi vous la faites mouuoir plus lentement, elle s'entortillera de ſoy meſme autour de ce piuot, & ainſi n'occupera plus tant d'eſpace.

De plus il faut remarquer que ces vapeurs peuuent eſtre plus ou moins preſſées ou eſtendues, & plus ou moins chaudes ou froides, & plus ou moins tranſparentes ou obſcures, & plus ou moins humides ou ſeiches vnefois que lautre. Car premiere-

Fig. 1. Copperplate from: Descartes, *Les Météores/Die Meteore*, ed. C. Zittel (Frankfurt am Main: 2006) 56.

sight.' The Vapour at C, on the other hand, begins to become opaque or obscure, because its particles do not obey the fine matter.

> When, however, the greatest part of their agitation is being used to propel many of them together in a single direction, they do not turn as strongly as usual, as they are seen at F, or, leaving the space E, they engender a wind which blows toward G.[52]

According to Descartes, the whole universe is entirely filled with fine currents of matter, so tiny as to be able to pass even through all supposedly solid bodies. In other words: The 'realistic'-looking formation of rocks is part of the general flow of matter. Consequently, all we see or feel in reality – solidity, warmth or colour – is an illusion, and the diagrammatical representation shows, though hypothetically, what might really be happening. The schematic and the realistic parts of the picture are, therefore, neither opposed, nor do they complete each other; instead, they illustrate a flowing, gradual transition of matter in the process of formation. Hence Descartes' explanation is anti-substantialistic – he does not presume that colours or solidity are innate qualities of an object, but the effects of motions in which the particles are brought due to their shape and under certain circumstances.

Descartes' description spans six pages; what has been sketched in the previous paragraph should, however, suffice to make clear on what principles it is based. Since in the last few years there has been a tendency to assume that scientific illustrations make things clear and give visible and invisible proofs, I wish to point out one issue: The picture proves nothing, but exemplifies a hypothesis that Descartes has established about the subvisible form of tiny particles of matter and the way they move. The picture is, in itself, not self-evident – text and picture exemplify each other and only make sense by their mutual interaction. Hence, the picture does not simply illustrate the text but has a cognitive function, insofar as it exemplifies in one glance and conceptualises as a picture the complex explanations of the different shapes and changes of the fine material. Here, this exemplification is effected by visualising the vapours composed of the fine material that 'can be more or less compressed or expanded, hot or cold, transparent or obscure, and moist or dry, at one time than at another.'[53] Descartes' morphological alphabet is to be demonstrated in application, which means that an

[52] Descartes, *Meteorology* 272 (AT VI 243).
[53] Descartes, *Meteorology* 271 (AT VI 244).

invisible process must be shown. An illustration must therefore fulfil a double function: it must make the invisible visible without concealing the character of process of what is depicted by a rigidly schematic, structurally isomeric model;[54] at the same time, an illustration must teach a different approach to nature: To dissect nature analytically with the eye, not into structures, but into moving and changing shapes of particles.[55]

It is only when, at the end of the text, all hypotheses of shape packed into this picture have proved of value in the different fields of practice and can be fitted together to a consistent explanation, that, according to Descartes, they can, as a whole, obtain an evidence-like status. This is a great concession to an experience-based, hypothetic-deductive procedure.[56]

Having exemplified his morphology, Descartes then attempts a more profound explanation of movement. His fourth discourse deals with the winds, to be explicit, the conditions of their formation and the degrees of their visibility and invisibility. He opens this discourse with a definition:

> Every tangible motion of the air is called wind, and all invisible and impalpable bodies are called air. Therefore, it is said, that when water very much thins and changes to very fine vapour, it has transformed itself to air, although all the air we breathe is, for the most part, composed of particles that differ greatly in their form and their much greater fineness from those of the water.[57]

For the explication of the genesis of the winds, Descartes calls to aid an experiment by Heron, known from the writings of Vitruv and Salomon

[54] Here the limits of Descartes' metaphorical images of machines become obvious. See Andres Vaccari's contribution to this volume.

[55] Cf. also: 'If this picture which thus gets inside our head still retains any resemblance with the objects from which it was taken, one must not, as I have made clear enough, imagine that this resemblance might give us an idea of them or that there might be other eyes in our brains by which we could perceive them. It is rather the movements that make up the picture.' Descartes, *Dioptrique* (AT VI 130).

[56] 'And in all this the experience so completely corroborates the explanation that I do not believe that anyone, who has thoroughly studied both, could possibly doubt the truth of my explanations. [...] Although each of these points alone makes the conclusion only probable, they can, all taken together, be considered as a proof. But had I attempted to deduce all these inferences in the way of the dialectics, I would have fatigued the hands of the printer and the eyes of the reader with an enormous volume.' Letter to Plempius for Fromondus of 3. 10. 1637 (AT I, 412–431, esp. 420).

[57] Descartes, *Meteorology* 287 (AT VI 265).

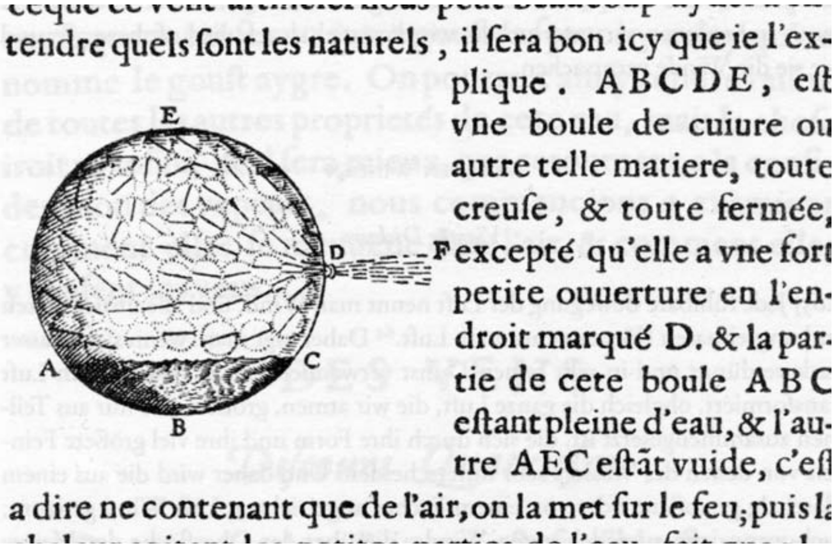
tendre quels ſont les naturels, il ſera bon icy que ie l'ex-
plique. ABCDE, eſt
vne boule de cuiure ou
autre telle matiere, toute
creuſe, & toute fermée,
excepté qu'elle a vne fort
petite ouuerture en l'en-
droit marqué D. & la par-
tie de cete boule ABC
eſtant pleine d'eau, & l'au-
tre AEC eſtãt vuide, c'eſt
a dire ne contenant que de l'air, on la met ſur le feu; puis la

Fig. 2. Copperplate from: Descartes, *Les Météores/Die Meteore*, ed. C. Zittel (Frankfurt am Main: 2006) 96.

de Caus. He has obviously not carried out this experiment himself, he simply tells of it – in contrast to the other observations in the *Meteorology* in the third person. It is about an Aeolipile:[58]

[58] This is an instrument that had already been described in the ancient world by Heron in his *Pneumatica* (hence also known as ball of Heron). Salomon de Caus likewise mentions it in a work on gardens, fountains, automata etc. (de Caus, *Les raison des forces mouvantes* (Frankfurt am Main: 1615)), which offered to the young Descartes a rich source of illustrative material to improve his understanding of mechanic coherences. Cf. Baltrusaitis, *Anamorphoses*; Boyer C.B., *The Rainbow: From Myth to Mathematics* (Princeton: 1959); Shea, *The magic of numbers and motion*, Werrett, "Wonders never cease". Lojacono (in Descartes, *Opere scientifiche*, 402 f.), however, points out that Vitruv should be mentioned as source, as he was particularly associated with the Aeolipile at the time and had also recurred to this instrument to explain the genesis of winds. Vitruv, *Vitruvii de architectura libri decem/Zehn Bücher über Architektur* (Darmstadt: 1996) (lib. 1, cap. VI). See also Descartes' letter to Mersenne of 25. 2. 1630 (AT I, 119–120), in which wind is described as vapour in motion with reference to the Aeolipile.

However, de Caus, for his part, directly referred to Heron and illustrated his works. In my opinion it is therefore more plausible to assume that Descartes received Heron by the intermediary of de Caus. Generally on the importance of the demonstration of machines for philosophies of technologies: Dolza L. – Verin H., "Figurer La mécanique: L' Énigme des théatres de machines de la renaissance", *Revue d'Histoire moderne et contemporaine* 51–52 (2004) 7–37.

The experiment attempts to demonstrate how even a small quantity of water can engender quite a strong wind. Descartes shows a picture of the Aeolipile in order to explain this process more accurately on the basis of his theory of matter. We see an entirely hollowed globe, at the bottom of which water moves in waves. Above the water rotate the particles of water we already know, escaping together in stretched form from the only and tiny opening D. At first the part ABC was filled with water and the other one, AEC, contained nothing but air. In this condition the ball was held over the fire. The heat then agitates the small particles of water, making many of them ascend above the edge of the water AC, where they expand, whirl about, knock each other about and try to get away from each other. And as they cannot detach themselves from one another unless some of them pass through the hole D, 'all the forces with which they push against each other conspire together to chase through the hole all the particles nearest to it; thus they cause a wind which blows from D toward F.'

Descartes here first presents a model by which the usually invisible process of the genesis of natural winds was to be made visible and comprehensible. He instantly admits, however, the limited reach of his model. In contrast to other models in science that refer in a structurally isomeric way to fixed natural phenomena and explain their structure and function, this can not, as a matter of principle, be applied to more complex processes. In nature, in contrast to the Aeolipile, the vapours do not only form on the surface of water, but likewise derive from humid earth, snow and clouds. Also, in nature the vapours could never be so completely enclosed as in an Aeolipile. The model has fulfilled its purpose and must now be abandoned in favour of a representation that is able to show, as in the first illustration, simultaneously induced processes which are contrary and have multiple causes.

The particles of matter, instead of being limited by the inner wall of the ball, now encounter obstacles like vapours, clouds or mountains, or a head wind that prevents their expanding uniformly in all directions. As these obstacles occur only randomly in the fashion shown in the picture, and as otherwise all factors vary depending on the region and the character of the natural surroundings, the season and temperature, a reliable scenario of what course the individual winds might take can never be given. The processes are mostly chaotic, one can only, according to Descartes, note the special dispositional circumstances, following his instructions; in this way, one can at least venture a prognosis for the regular main winds.

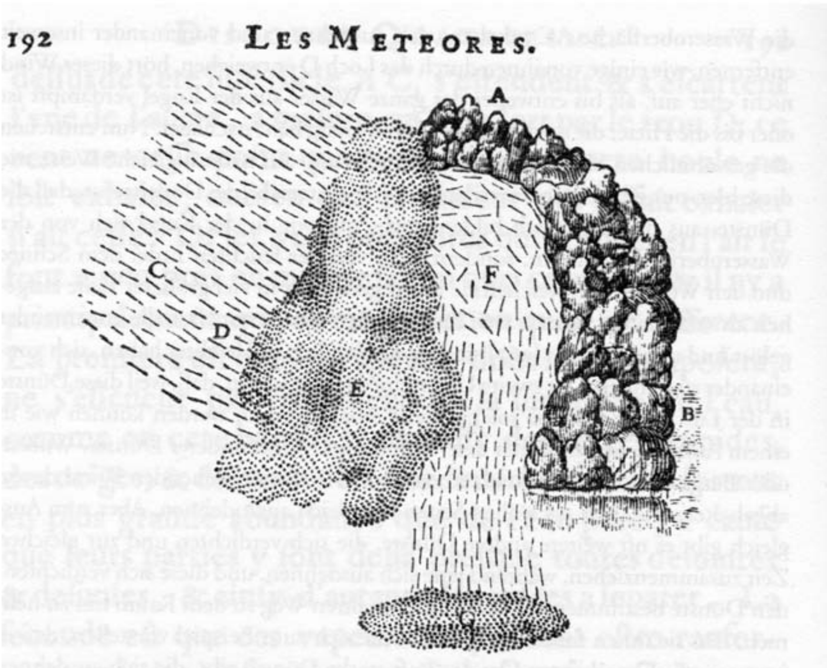

Fig. 3. Copperplate from: Descartes, *Les Météores/Die Meteore*, ed. C. Zittel (Frankfurt am Main: 2006) 100.

IX.

The piling up of clouds collaterally leads to phenomena related to thunderstorms, which Descartes deals with in the 7th Discourse. By a quick succession of up-and-down-movements within a cloud, as well as by the enclosure of exhalations between two clouds or within one, tensions are created which, in turn, engender violent winds or, by an inflammation of the exhalations, thunderstorms, lightening and ball lightening. It is Descartes' conviction that, whereas vapours can only thicken to ice or water, oily exhalations can, under the necessary impact, even transform themselves to solid bodies. Here again he turns to experiences from every-day life.[59] As cream can be battered to butter,

[59] CF. the introduction to this volume.

exhalations enclosed in clouds could be changed to manna by a violent wind, and 'a thunderbolt can sometimes change into a very hard rock, which breaks and fractures everything it encounters, if among these very penetrating exhalations there exist a quantity of those others which are slippery and sulphurous.'[60] Descartes even goes so far as to believe it possible that under certain circumstances, when the clouds strongly press on the exhalations, a material can form from them

> like milk, or blood or flesh; or else in being burned, becomes such that we take for iron, or for rocks, or finally, in becoming corrupted, engenders certain small animals in very little time. Thus we often read, among the miracles, that it rained iron, or blood, or locusts or similar things.

At this point, he also explains, *en passant*, the ghost squadrons that contemporaries observed in the sky. They are, in his eyes, a combination of many little clouds resembling soldiers. Enclosed in them are exhalations creating little fires. The clouds therefore produce such fires and noises – thence the impression that these soldiers are fighting.[61] Descartes does not deny such miraculous apparitions, but accepts and accounts for them.

X.

To better understand Descartes' weather-*bricolage*, I would like to take a closer look at one particular account: Descartes' description of snow from the 6th Discourse of the *Meteorology*. Unlike Kepler, who had described the geometrical structure of snow crystals only few years before, Descartes is little interested in the hexagonal form as such. His aim is not to prove a general principle of geometrical order or a law of nature from the surprising regularity of the hexagonal crystals; he wishes to explain how these forms can come about. For this purpose, as it turns out, it is order itself which proves problematic, because the regularity of the crystals is too marked to be explained by coincidental combinations of particles. Descartes therefore departs from the procedure hitherto adopted in his text, which had implied the deduction of phenomena by combining hypothetically assumed forms of particles, and invokes facts of observation. It is remarkable that for Descartes

[60] Descartes, *Meteorology*, AT VI 327.
[61] Descartes, *Meteorology*, AT VI 330.

difficulties begin the very moment sublunary phenomena occur with too much regularity. At that point he changes the mode of his depiction in favour of a personal narrative, covering ten pages,[62] in which he describes, minutely and phenomenologically precisely, his observations of snow, and, what is more, the separate phases of his own processes of perception. I know of no comparable account of the observation of nature before or at that time, neither in natural philosophy nor in treatises on painting. The treatise on snow is too long to be quoted in full length, but I will try to give an impression of it and to make clear its rhetorical structure:

After general statements concerning the observation of snow, hail and ice on the grounds of the hypotheses mentioned, Descartes introduces the subject as follows:

> But so that you will not think that I speak of these matters only from opinion, I want to report to you an observation I made during the past winter of 1635. On the fourth of February, the air having previously been extremely cold, there fell in the evening in Amsterdam (where I was at that time) a little frost, that is rain which froze upon striking the earth.[63]

It is remarkable, that it is by the very transition from an objective description to a first-person-narrative that Descartes attempts to lend credibility to the statements put forth as more than mere opinion. The introduction is followed by a minute analysis of his observation and by an illustration showing the different shapes of the snow crystals. This picture is, as many others in the text, printed several times in the book, in this case thrice and thus called to mind during the perusal. While he explains the meteors, Descartes tries to gain, and permanently keep, control over the readers' imagination. He also assumes that the repeated observation of a picture leaves a deeper impression on the memory, which is to be lastingly formed by the pictures.

In the text Descartes repeatedly refers to the picture which depicts to the reader the size and quality a snow crystal was to have had at a certain time in its development. By the constant rhetorical hints to details in the illustrations, the reader is obliged to switch permanently between the picture and the text:

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[62] AT VI, 298–308; Descartes, *Meteorology* 312–319. All the following quotations are taken from this section in this volume; the accentuations were added by me.

[63] Descartes, *Meteorology* 312.

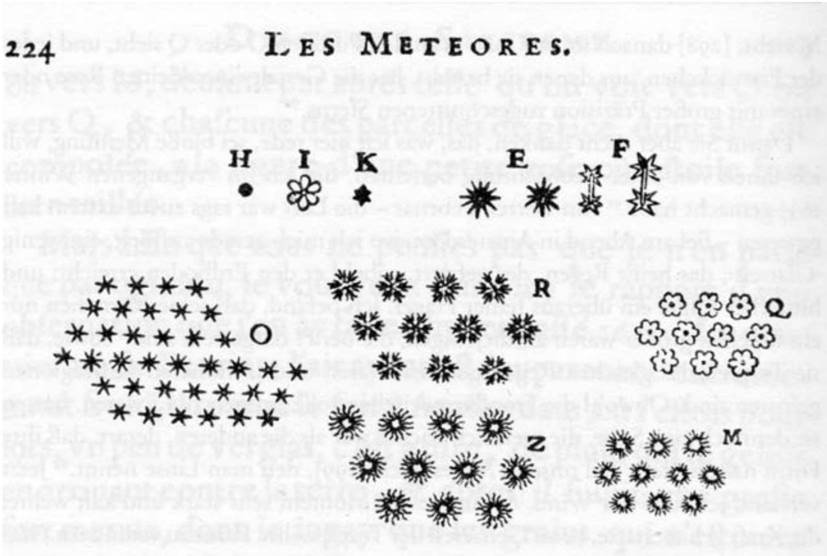

Fig. 4. Copperplate from: Descartes, *Les Météores/Die Meteore*, ed. C. Zittel (Frankfurt am Main: 2006) 164.

> And afterwards a very fine hail fell, whose particles, which were slightly larger than those represented at H, I judged to be drops of the same rain, which were frozen high in the air [...] (Ibid. 312).

This leads Descartes to a first conclusion: 'From this I understood that the wind, which was quite strong and very cold, had the necessary force so to change the shape of the drops in freezing them.'

This observation is followed by another, which has to be compared with the first. The narrative is dominated by expressions of surprise that are changed to comprehension only with difficulty:

> But what *astonished me most of all* was that among those grains which fell last, I noticed some which had six tiny teeth around them, similar to those in the wheels of clocks, such as you see at I. And these teeth were very white, like sugar, whereas the grains, which were of transparent ice, seemed to be nearly black, and the teeth appeared obviously to be made of a very fine snow which attached itself around the grains after they were formed, as white frost attaches itself around plants. And *I understood this all the more clearly because right at the end* I ran across one or two of them which had innumerable tiny hairs about them, made of a paler and finer snow than that of the small teeth around the others, [...]. I was at great pain to imagine what could have formed and proportioned these six teeth around each grain so exactly [...] (Ibid. 312).

Now Descartes introduces his first auxiliary hypothesis:

> *until I finally considered* that this wind had easily been able to carry some of the grains below or away from some cloud, and support them there because they were small enough (Ibid. 313).

Some first conclusions can now be drawn from the observations, and the explanation of the phenomenon – being at first no more than probable – can be canvassed.

> and that there they were obliged to arrange themselves in such a way that each was surrounded with six others in the same plane, following the normal order of nature. And I realized, moreover, that it was very likely that the heat, which must have been in the air slightly beforehand, in order to cause the rain that I had observed, had also emitted certain vapours which this same wind had blown against these grains, where they were frozen in the form of very slender, tiny hairs; and perhaps [. . .] (Ibid. 313)

The next day, further observations are made:

> The next morning, at approximately eight o' clock I again observed another kind of hail, or rather snow [. . .] but so perfectly formed in hexagons, and of which the six sides were so straight, and the six angles so equal, that it is impossible for men to make anything so exact (Ibid.).

Having trained the eye the day before, he can rapidly come to a judgement by sight, and name the remaining difficulties:

> I *saw immediately* that these blades must first have been small lumps of ice, [. . .] And I saw that at the same time this wind [. . .] *There only remained the slight difficulty that these lumps of ice*, [. . .] (Ibid. 314).

Descartes tells how subsequent observations strengthened the basis on which his hypotheses of explanation were founded. From this he draws further conclusions, self-reassurance changes to absolute assurance. The phenomena can now be made comprehensible and be classed within the theoretical frame by the means of analogies and comparisons. Everything now becomes easily comprehensible; recurring expressions now testify to Descartes' increasing assurance in perception and judgement:

> But *I soon satisfied myself* about this by considering the way in which the wind continually agitates and successively bends all the particles of the surface of water by flowing over it, without making it rough or uneven by doing so. For I recognized from that that the wind *infallibly* causes the surfaces of clouds to bend and undulate in the same way, [. . .] it was

> easy to me *to judge* that [...]. *I did not doubt that* [...] all this *gave me occasion to consider* [...] And *I was not astonished* [...] *fore I thought* [...] *neither I was astonished to see* [...] *I judged that the cause of this was* [...] Finally, *I was not surprised* at those double stars having twelve radii, which fell afterwards; *for I judged* [...] All the causes of these are easy to understand (Ibid. 314–316).

At the end he tells of an observation he was able to make three days later and which was finally to confirm his description:

> Finally, three days later, seeing snow composed completely of tiny knots or lumps surrounded with a great number of intermingled hairs, which did not have at all the shape of stars, *I confirmed my belief* in all that I had imagined concerning this matter (Ibid. 319).

The exact indication of the time of day and of the circumstances of observation, as well as the minute self-reflective description of his own process of observation and perception augment the credibility of the report – they enable the reader to reconstruct how the explanations are found and to practice them for their own use. Not the least detail may therefore be omitted. Observation, experiments, description and depiction interlock, the eye and the imagination are trained in analytical vision by the vivid descriptions and the illustrations. They eye must learn to dissect a snow flake into its components, which means grasping it morphologically, so that it will become by degrees more simple to establish hypotheses of explanation and to come to inferences about the processes of formation. It is easier and quicker to come to such conclusions the more knowledge the eye has accumulated. The hypotheses of form are changed to convictions, irritation and astonishment end in reassuring knowledge.

XI.

The special qualities of sublunary phenomena made Descartes design his text on the meteors as a school of seeing. In order to grasp chaotic processes in theory, the eye has to be trained, step by step, for minute empirical observation; it is also necessary to develop a new language for description and pictures and a very wide conception of deduction, based on concrete observations and exact imagination. Criteria such as 'fictional' versus 'conform to reality' are therefore no longer of value as historic-systematic categories of philosophic concepts of experience.

The criterion of consistence between unproblematic empirical descriptions and reality is not an appropriate measure in this case; the features of reality are self-determinedly established by the art of explorative observation, imaginative description and experimental *bricolage*.

In short: Descartes was a Baconian. Not so much the laboratory, but nature itself is the workshop of the new science – this is as true for Bacon as it is for Descartes. Bacon himself gives the best characterisation of this aesthetically playful style of experimenting and thought in his principal work *Sylva Sylvarum*:

> For this writing of our '*Sylva Sylvarum*' is, to speak properly, not natural history, but a high kind of natural magic. For it is not a description only of nature, but a breaking of nature into great and strange works.[64]

[64] Francis Bacon, *Sylva Sylvarum* (London: 1627), Cent. 93.

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PART IV

BACON'S LEGACY: THE IMPACT FOR THE ARTS AND SCIENCES

THE POET AND THE PHILOSOPHER: FRANCIS BACON AND GEORG PHILIPP HARSDÖRFFER

Berthold Heinecke

When in 1698 August Hermann Francke (1663–1727) began drawing up a curriculum for the institutions he had established in Halle, he turned to his friend Ehrenfried Walther von Tschirnhaus (1651–1708) for advice regarding the natural sciences and mathematics program. The result, a short text published for the first time in 1700 and much appreciated by Leibniz, was entitled *Gründliche Anleitung zu nützlichen Wissenschaften, absonderlich zu der Mathesi und Physica, wie sie anitzo von den Gelehrtesten abgehandelt werden*.[1] Here, Tschirnhaus provides a list of suggested reading to introduce young students to the field. 'Aber hierzu,' he writes,

> müssen sensuale experienzien kommen, die eine Verwunderung excitiren, und also die natürliche Begierde so bey allen Menschen ist zu der Wahrheit [...] excitiren, und zugleich von solchem Nutzen sind, daß sie die Fundamenta aller nützlichen Wissenschafften [...] includiren.[2]

Included on the list is a text which apparently fulfilled these requirements, the *Philosophische und mathematische Erquickstunden* [Philosophical and Mathematical Recreation Hours] by Daniel Schwenter and Georg Philipp Harsdörffer.

Though his literary renown had long since faded, Harsdörffer's natural scientific work – strongly influenced in its central line of thought, as I will argue here, by Francis Bacon – apparently still commanded an audience. Like Bacon, Tschirnhaus, too, through the critical development of Bacon's thought, saw the *ars inveniendi* as his chief objective.[3]

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[1] Tschirnhaus E.W., *Gründliche Anleitung zu nützlichen Wissenschaften, absonderlich zu der Mathesi und Physica, wie sie anitzo von den Gelehrtesten abgehandelt werden*, ed. E. Winter (Stuttgart-Bad Cannstatt: 1967), XVI–XX. The version referred to here is the fourth expanded and corrected edition of 1729. I am grateful to Staci von Boeckmann for her help in translating this essay from German.

[2] Ibid., 17–18.

[3] Peursen C.A. van, "E.W. von Tschirnhaus and the Ars Inveniendi", *Journal of the History of Ideas* 54 (1993) 395–410; Wollgast S.: "Ehrenfried Walther von Tschirnhaus und die deutsche Frühaufklärung", in Wollgast S., *Vergessene und Verkannte. Zur Philosophie*

It is the goal of the present study to trace the influence of Bacon's thought on Harsdörffer in an effort to illuminate the history of Bacon's reception in Germany and, above all, the paths through which his thought was disseminated. This undertaking simultaneously addresses the question of how contemporary scientific discussion was conveyed to the educated gentry and aristocracy.

Before beginning, I would like to comment briefly on the current state of research on this question. A thorough examination of Bacon's influence in Germany, particularly with regard to the development of early natural science, has yet to be undertaken. In his 1914 book examining the literary ties between Germany and England, Gilbert Waterhouse points to the relationship of Bacon's work to German baroque literature, specifically that of Johann Wilhelm von Stubenberg, Daniel Georg Morhof, Johann Balthasar Schupp and Georg Philipp Harsdörffer, coming to the conclusion: '*That Bacon was held in the highest esteem in Germany during the seventeenth century is clear from the nature of the numerous references to him in almost every branch of literature.*'[4] In Germany, the work of Helmut Minkowski in the 1930s bears mention. Minkowski devoted his research to the influence of Bacon's *Nova Atlantis* and its significance for the founding of the *Academia Naturae Curiosorum* in Schweinfurt in 1652, without, however, any closer examination of Harsdörffer.[5]

In his introduction to the new edition of the *Deliciae Physico-Mathematicae* by Daniel Schwenter and Georg Philipp Harsdörffer, Jörg Jochen Berns also points to the special significance of Bacon. According to Berns, Francis Bacon is the most important theoretical and natural scientific figure for Harsdörffer,[6] indeed, he suggests Bacon was for him the ultimate epistemological and philosophical authority.[7] Nevertheless, we

und Geistesentwicklung in Deutschland zwischen Reformation und Frühaufklärung (Berlin: 1993) 254–310; Wollgast S., "Zum Methoden- und Erfahrungsproblem bei E.W. von Tschirnhaus", in Hecht H. (ed.), *Gottfried Wilhelm Leibniz im philosophischen Diskurs über Geometrie und Erfahrung* (Berlin: 1991) 105–129.

[4] Waterhouse G., *The Literary Relations of England and Germany in the Seventeenth Century* (Cambridge: 1914) 88.

[5] Minkowski H., "Die Neu-Atlantis des Francis Bacon und die Leopoldina-Carolina", *Archiv für Kulturgeschichte* 26 (1936) 283–295; Idem, "Die geistesgeschichtliche und die literarische Nachfolge der Neu-Atlantis des Francis Bacon", *Neophilologus* 22 (1937) 120–39; 185–200.

[6] Harsdörffer G.P. – Schwenter D., *Deliciae Physico-Mathematicae oder Mathematische und Philosophische Erquickstunden*, ed. J.J. Berns, 3 vols. (Frankfurt am Main: 1991) vol. I, XXI.

[7] Ibid., vol. I, XXV.

do not concur in his assessment of Harsdörffer's relationship to the use and significance of experiment, according to which Harsdörffer was no longer interested in experiment but rather in the game and, above all, in illusionism and the creation of sensory tricks. Though Harsdörffer's text is conceived expressly for mental recreation and edification, it nevertheless represents a serious popularization of contemporary knowledge of the natural world, without going into the specific detail appropriate to a more specialist readership. This becomes especially apparent in comparisons of the *Erquickstunden* with similarly positioned works of the second half of the 17th century, such as Erasmus Franciscis' (1627–1694) *Die lustige Schau-Bühne von allerhand Curiositäten*, Johann Michael Schwimmer's (1638–1704) *Kurtzweiliger und physicalischer Zeitvertreiber* or Gottfried Voigt's (1644–1682) *Physicalischer Zeit-Vertreiber*,[8] which do not attain the level of Harsdörffer's work. Harsdörffer is absolutely clear of the central role of experiment for new natural research.

Peter Hess addresses this same problematic in his essay, *Neoplatonismus und Bacon-Rezeption: Naturphilosophie bei Harsdörffer*. Hess calls attention, among other things, to the pedagogical quality of Harsdörffer's text. Yet, his argument that Harsdörffer was hardly read by specialists is unconvincing, since the influence especially of the *Erquickstunden* in the second half of the 17th century remains largely unexamined. After all, nearly 50 years after his death, Harsdörffer continued to be counted among the greatest mathematicians, whereby mathematics must be understood in its historically specific parameters.[9] Likewise, the assertion must also be challenged that astrology, indeed, Neoplatonic thought in general, played a central role in Harsdörffer's thought. There is no lack of critical commentary on the subject in the *Erquickstunden*, while the more poetic treatment of the subject in the *Gesprächspiele* is no counterargument. The notion that Harsdörffer's natural philosophy represents a marked step backward in comparison to Bacon is simply unsupportable.[10] Much more, his work stands out in particular for its relatively comprehensive representation of the state of natural philosophy around 1650. In her

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[8] Francisci E., *Die lustige Schau-Bühne von allerhand Curiositäten*, 3 vols. (Nuremberg: 1669–1673); Schwimmer J.M., *Kurtzweiliger und physicalischer Zeitvertreiber* (Jehna: 1676); Voigt, G., *Physicalischer Zeit-Vertreiber* [...] (Rostock: 1670).

[9] Reimmann J.F., *Versuch einer Einleitung in die Historiam Literariam insgemein und derer Teutschen insonderheit*, 6 vols. (Halle: 1708–1713) vol. IV, 119.

[10] Hess S., "Neoplatonismus und Bacon – Rezeption: Naturphilosophie bei Harsdörffer", *Morgen-Glantz* 13 (2003) 321–349.

essay on Harsdörffer and Kaspar Schott, Diana Trinkner[11] emphasizes the central importance of Bacon for Harsdörffer's epistemology, pointing specifically to the *Erquickstunden*.

In his article *The Reception of Francis Bacon in 17th Century German Philosophy*, Jürgen Klein attempts to offer a thorough overview of Bacon's influence in Germany. With respect to Harsdörffer, he points to the importance of the reception of *De sapientia veterum* for his interpretation of pagan mythology – above all the Pan mythos. Jörg Jochen Berns, too, examines this question in *Gott und Götter. Harsdörffers Mythenkritik und der Pan-Theismus der Pegnitzschäfer unter dem Einfluß Francis Bacons*. Berns shows through detailed textual comparison that the Pegnitz Sheperds, Harsdörffer in particular, derived all aspects of their Pan interpretation from Francis Bacon. According to Berns, the interest of the Pegnitz Shepherds in Bacon's mythical interpretations encompassed chiefly two perspectives: a natural scientific one (including questions of physico-theology and pantheism) and a patriotic one.[12] Berns reaches the overall conclusion that there was no aesthetic program in Germany which so decisively sought its legitimation in Baconian philosophy than that of the Pegnitz Shepherds.[13] Here, he calls attention to the attempt to make Germany the new home of the arcadian Pan: A development, it must be mentioned, that runs parallel to the awakening interest in the archaeological evidence of prehistoric Germany and the attempt to trace the geneological roots of the German dynasty through the old *Germanen* to Troy.[14] Berns also thematizes the relationship to the arcadian utopia, to which we will return later.

[11] Trinkner D., "Gedankenflug und Lichtmetaphysik: zu Georg Philipp Harsdörffers und Kaspar Schotts Erkenntnislehre", *Morgen-Glantz* 7 (1997) 311–339.

[12] Berns J.J., "Gott und die Götter. Harsdörffers Mythenkritik und der Pan-Theismus der Pegnitzschäfer unter dem Einfluß Francis Bacons", in Battafarano I. (ed.), *Georg Philipp Harsdörffer. Ein deutscher Dichter und europäischer Gelehrter* (Bern: 1991) 23–81, 55.

[13] Ibid., 70.

[14] Hermand J. – Niedermeier M., *Revolutio Germanica. Die Sehnsucht nach der alten Freiheit der Germanen 1750–1820* (Frankfurt am Main: 2002).

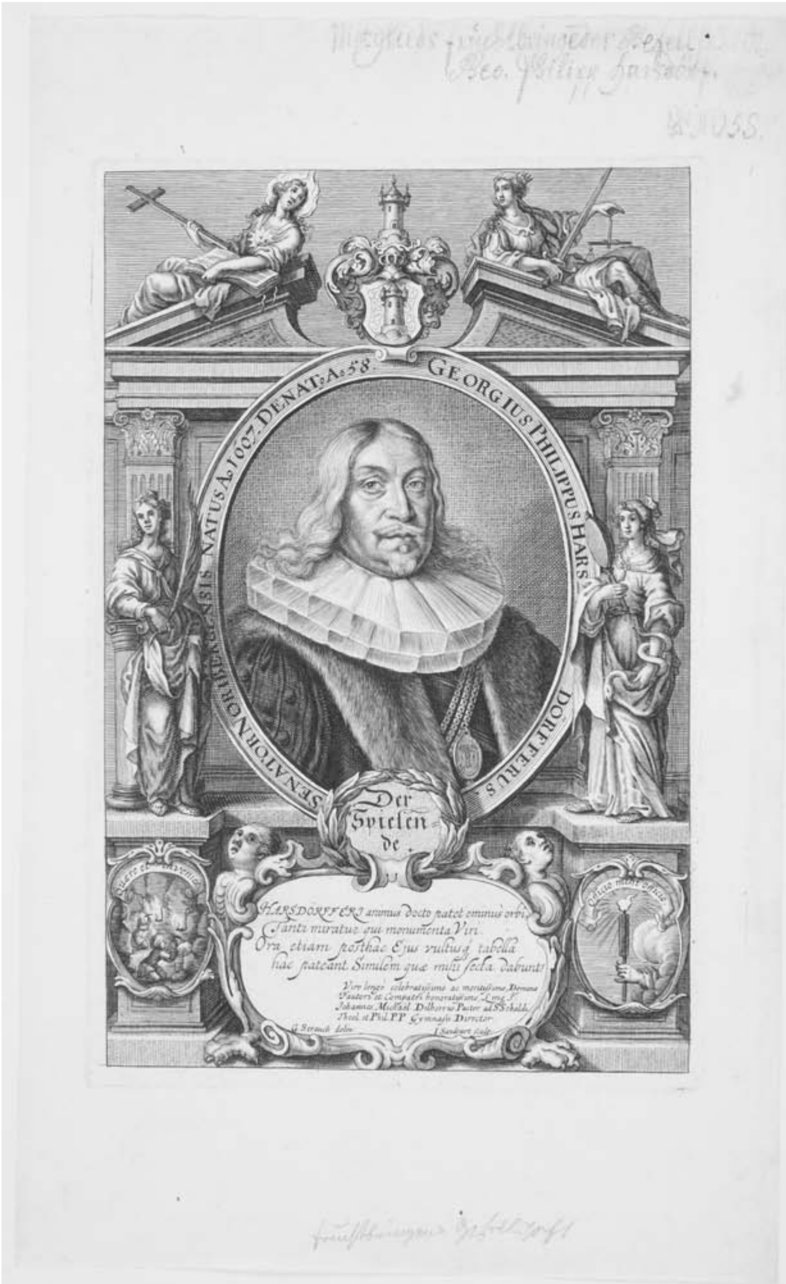

Fig. 1. Portrait of Georg Philipp Harsdörffer, etching (Herzog August Bibliothek Wolfenbüttel: Porträt A 8895).

Bacon through the Eyes of Harsdörffer – An Overview

Preliminary Remarks

Harsdörffer's written production is extraordinarily voluminous; Georg Adolf Narciss has counted more than 20,000 printed pages. Many works are multi-volume, appearing in multiple editions and versions. The following overview of the presentation of Baconian philosphy in Harsdörffer's thought does not, therefore, pretend to be comprehensive. Instead, our focus will be on those works in which Harsdörffer deals with natural science, chiefly, the *Erquickstunden*.

The Frauenzimmer Gesprächspiele [Ladies' Conversation Games]

By the time Harsdörffer travelled to England during his *peregrinatio academica* from 1627 to 1632, Francis Bacon was already dead. Yet, it is hardly imaginable that the young man from Nuremberg had not heard of Bacon and his rather publicly conspicuous fate. It is likely that Harsdörffer had already become familiar with Bacon during his studies with Michael Bernegger. It is certain, in any case, that Bacon is present in Harsdörffer's work from the very beginning, as can be seen in the monumental text of the *Frauenzimmergesprächspiele* published in 1641. The work is, at once, an encyclopedia of dialogue forms, drawing on the dialogical literature of antiquity, as well as Italian and French precursors. Following specific rules of conduct, three women and three men hold discussions on every conceivable topic of human life. According to Karl Helmer,[15] the work is intended to convey instruction on good behavior and proper speech, as well as pleasant and useful teaching and knowledge. More than 800 titles are cited in the dialogues of which nearly half are of Roman origin.[16] According to Irmgard Böttcher, it

[15] Helmer K., *Weltordnung und Bildung. Versuch einer kosmologischen Grundlegung barocken Erziehungsdenkens bei Georg Philipp Harsdörffer*, Peideia. Studien zur systematischen Pädagogik 7 (Frankfurt am Main-Bern: 1982) 51; Zeller R., *Spiel und Konversation im Barock. Untersuchungen zu Harsdörffers "Gesprächspielen"*, Quellen und Forschungen zur Sprach- und Kulturgeschichte der germanischen Völker, Neue Folge 58, ed. S. Sonderegger (Berlin-New York: 1974).

[16] Böttcher I., "Der Nürnberger Georg Philipp Harsdörffer", in Steinhagen, H. – Wiese B. von (eds.), *Deutsche Dichter des 17. Jahrhunderts. Ihr Leben und Werk* (Berlin: 1984) 289–346, 298.

was Harsdörffer who introduced this particular literary form, marrying game and dialogue, to the German-speaking world.[17]

The foundation and point-of-departure of the massive text is Horace's poetic formulation: '*prodesse et delectare*', use and delight. Here, too, belongs his saying, borrowed from the Roman philosopher Seneca (4 A.C./1–65): '*Miseri mortales, nisi quotidie inuenirent, quod discerent.*':[18] Terrible, when people don't find something to learn every day. This represents the largely didactic-pedagogical character of the work, which is also apparent in his *Nathan und Jotham* published shortly before the *Erquickstunden*.[19] In the *Gesprächspiele*, a variety of topics of everyday life, worldly wisdom and scientific knowledge are dealt with in short, often allegorical stories. Here, at least with respect to the reception of Bacon, we must part ways with Rosmarie Zeller, who maintains that the dialogues represent only a survey of general knowledge.[20]

The city of Nuremberg and Harsdörffer, in particular, play a significant role in the popularization of Bacon in the German-speaking world. Bacon was hardly mentioned by the great renovators of science in the first half of the 17th century, so that the proliferation of his philosophy of science took place, significantly, through other avenues.[21] Bibliographic references to Bacon's work, citations and allusions can be found in all eight volumes of the *Gesprächspiele.* While we cannot attain a comprehensive overview of such appearances of Baconian philosophy, for they are contained in the work of other authors as well, with regard to the number of direct references, the majority refer to the 1635 edition of *De Dignitate et Augmentis Scientiarum*. This is also the only text named explicitly with place and year of publication in the bibliography of Volume 2. Up until 1649, the year of publication of the last volume of the *Gesprächspiele*, five Latin, three French, and two English editions of this work appear.[22] The second most cited of Bacon's works is *De Sapientia Veterum* (first edition London 1609). This text, too, belongs to the most

[17] Ibid., 301.
[18] Will G.A., *Nürnbergisches Gelehrten-Lexicon*, 8 vols. (Nuremberg-Altdorf: 1755–1808) vol. 2, 34–39, 35.
[19] Harsdörffer G.P., *Nathan und Jotham: das ist Geistliche und Weltliche Lehrgedichte*, 2 vols. (Nuremberg: 1659), ed. G. van Gemert (Frankfurt am Main: 1991).
[20] Zeller R., *Spiel und Konversation im Barock. Untersuchungen zu Harsdörffers "Gesprächspielen"* 6.
[21] Cf. Krohn W., *Francis Bacon* (Munich: 1987) 177.
[22] Gibson R.W., *Francis Bacon. A Bibliography of his Works and of Baconiana to the year 1750* (Oxford: 1950) XV.

often reprinted works, among which is a German edition bearing the title, *Francisci Baconi, Grafens von Verulamio, Fürtrefflicher Staats- Vernunfft- und Sitten-Lehr-Schrifften* [...], published in 1654 in Nuremberg by Endter. Harsdörffer composed a poem under his pseudonym in the Fruitbearing Society explaining the title copper-plate. A translation was done by Johann Wilhelm von Stubenberg (1619–1663), a fellow member of the society, but not of the *Pegnesischer Blumenorden* [Flower Order at the river Pegnitz], under the pseudonym 'der Unglückselige'. The copper plate shows four men standing at a small pond, one of whom – likely based on the figure of Bacon – points with a stick to the reflection of the sun. Harsdörffer's poem interprets this as the identification of the sun with Francis Bacon.

Bacon's *Historia Ventorum* (first edition London 1622) is cited once; the *Historia Vitae et Mortis* (first edition London 1623) two times. Only one direct reference is made to *Novum Organum* (first edition 1620), for which Bacon is most well known today. This offers a convincing reflection of the history of reception in the 17th century: until 1650, only four editions of this work and no translations had been published. The *Essays* are only expressly mentioned once, although they are the most frequently reprinted of Bacon's works in the 17th century. A German edition of this work was also published in 1654 by Endter in Nuremberg under the title *Francisci Baconis Grafens von Verulamio, weiland Englischen Reichscantzlers Getreue Reden: die Sitten- Regiments- und Haußlehre betreffend* [...], for which Harsdörffer compiled a table of contents in verse entitled *Poetischer Aufzug/den Inhalt der Getreuen Reden dieses Büchleins vorstellend.* In addition to his continual references to Bacon in his own work, Harsdörffer also contributed in this way to the popularization of Bacon's thought. The text was translated, once again, by Johann Wilhelm von Stubenberg. Doubtless, Harsdörffer played an important role in prompting the two Nuremberg editions.

Because of the detailed references made to these works, Bacon's *De Sapientia Veterum* and *Nova Atlantis* hold special significance. In Volume IV of the *Gesprächspiele*, Harsdörffer provides a detailed description of the Pan mythos following Bacon's interpretation in *De Sapientia Veterum*[23] and cites *Nova Atlantis* in marginalia. Volume VII contains a description of the house of Salomon from *Nova Atlantis*. It is somewhat perplexing

[23] Berns J.J., "Gott und die Götter. Harsdörffers Mythenkritik und der Pan-Theismus der Pegnitzschäfer unter dem Einfluß Francis Bacons" 23–81.

Fig. 2. Title copper-plate of *Francisci Baconi, Grafens von Verulamio, Fürtrefflicher Staats- Vernunfft- und Sitten-Lehr-Schrifften* [...] (Nuremberg: 1654) (Herzog August Bibliothek Wolfenbüttel: Xb 100).

in this context that there is no direct reference to *Sylva Sylvarum*, since *Nova Atlantis* is printed in the appendix to the first London edition of 1626. Not to mention that *Sylva Sylvarum* belongs to the more popular of Bacon's works in the first half of the 17th century, with six English, two Latin and one French edition appearing by 1650. It can, thus, hardly be assumed that Harsdörffer was somehow unfamiliar with this text. Moreover, there are obvious parallels between this work and his own *Erquickstunden*.

The Erquickstunden

We are dealing here with a three-volume work with a total of more than 1800 printed pages, published by Endter in Nuremberg between 1651 and 1653. Volume I was first published in Nuremberg in 1636 by Daniel Schwenter, who had been Harsdörffer's teacher in Altdorf. In 1651 the text was newly edited by Harsdörffer as the first volume of this continued work. Schwenter took as a model for his edition the similarly designed text of the French Jesuit Jean Leurechon (1591–1670), published in 1624.[24] Leurechon's book is chiefly a book of recreational mathematics with a didactical orientation.[25] Whereby, we must also add that the concept of mathematics employed here is much broader than modern conceptions. Simply put, one might say that everything bearing any sort of relation to quantification counted as part of mathematical science.[26] Schwenter adopts Leurechon's basic concept, expanding the text, however, in respect to its size and range of topics. Instead of 150 problems and examples in the French text, his edition contains some

[24] Cf. Jean Leurechon, *Récréation mathématicque, composée de plusieurs problèmes plaisants et facetievx, En faict d' Arithméticque, Géométrie, Mechanicque, Opticque, et autres parties de ces belles sciences* (Pont-à-Mousson: 1624); Harsdörffer G.P. – Schwenter D., *Deliciae Physico-Mathematicae oder Mathematische und Philosophische Erquickstunden* vol. I XIV–XV; Rudel K., "Harsdörffers mathematisch-naturphilosophische Schriften", in Bischoff T. – Schmidt A. (eds.), *Festschrift zur 250jährigen Jubelfeier des Pegnesischen Blumenordens: gegründet in Nürnberg am 16. Oktober 1644* (Nuremberg: 1894) 301–403.

[25] Ed. Gillispie C.C., *Dictionary of Scientific Biography*, 18 vols. (New York: 1970–1990) vol. 8, 271; Heeffer A., "Récréations Mathématiques (1624). A study on its authorship, sources and influence", *Preprint History of Science Society Annual Conference Austin Texas 2004*, 1–43. The authorship of Leurechon was a subject of continual debate. Heeffer has now reached the conclusion that it was not Leurechon but Jean Appier dit Hanzelet (1596–1647), a printer and engraver, who authored the text. Heeffer has devoted his research to the sources, content and influence of this text.

[26] Christian Wolff, *Mathematisches Lexicon* (Leipzig: 1716) 863–864.

663 taken from a variety of contemporary authors.[27] He divides his book into 16 parts, beginning with arithmetic, then on to geometry, stereometry, music, optics, the art of mirror making, astronomy, clock making and magnetism, the art of making balances and weights, motion, fire and heat, pneumatics, hydraulics, writing, architecture and, finally, chemistry. Each part of the collection begins with a brief introduction to the area of specialization, followed by the problems, often including illustrations. The highly modern, even future-oriented feature of this layout is that Schwenter combines theoretical disciplines from the classical structure of the Quadrivium of the artistic faculty with new fields of specialization in engineering. The German language of the text makes it clear that the target audience is not academics but rather the educated gentry and hand workers.

Schwenter's book is characterized by the elevation of the *artes mechanicae*,[28] which coincides with the aforementioned significance of technology for Nuremberg's economy. Aside from the numerous names appearing in his index of authors, Schwenter relies for his content primarily on practitioners of mathematics and natural science, so that Jörg Jochen Berns in his introduction to the new edition of Schwenter's text rightfully concludes that Schwenter was concerned, above all, with the practical application of knowledge and not theoretical innovation.[29]

In 1651 and 1653 Harsdörffer expands Schwenter's work with two additional volumes. The basic construction remains unchanged, with chapters on astronomy, hydraulics and chemistry following those on mathematics and the surveying of land. The volumes are different, however, with regard to the sources from which he derived his examples. Here, the accent shifts to the top names of the new 17th-century science from Galileo to Kepler, Descartes (1596–1650) and Mersenne (1588–1648) through to Comenius (1592–1670) and Athanasius Kircher

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[27] Harsdörffer – Schwenter, *Deliciae Physico-Mathematicae oder Mathematische und Philosophische Erquickstunden* vol. I, 7–12.

[28] Cf. Bacher J., "Artes Mechanicae", in Holländer H. (ed.), *Erkenntnis, Erfindung Konstruktion. Studien zur Bildgeschichte von Naturwissenschaft und Technik vom 16. bis zum 19. Jahrhundert* (Berlin: 2000) 35–50; Blumenberg H., "Nachahmung der Natur. Zur Vorgeschichte der Idee des schöpferischen Menschen", *Studium Generale* 10 (1957) 266–283; Böhme G. – Daele W. van den – Krohn W., *Experimentelle Philosophie. Ursprünge autonomer Wissenschaftsentwicklung* (Frankfurt am Main: 1977) 63–67; Heidelberger M. – Thiessen S., *Natur und Erfahrung. Von der mittelalterlichen zur neuzeitlichen Naturwissenschaft* (Hamburg: 1981) 52–61.

[29] Harsdörffer – Schwenter, *Deliciae Physico-Mathematicae oder Mathematische und Philosophische Erquickstunden* vol. I, XIX.

(1602–1680).[30] Here, Harsdörffer's pan-European education becomes clear. Of the 146 authors listed at the end of the third volume, not all are equally important, as was already the case with Schwenter. He sees the benefit of his book especially in the fact that, of all the texts available, he has compiled the work of the most interesting authors, which is especially useful for those who do not have the money to buy all of these texts separately or who have not mastered foreign languages. Again, Francis Bacon along with Athanasius Kircher are among to the most frequently cited authors. Though Harsdörffer's text is intended as popular scientific entertainment, its content nevertheless reflects a serious presentation of the contemporary level of knowledge.

Aside from direct and indirect references to Bacon, the introductions to both volumes deserve special attention, expressing, as they do, Harsdörffer's philosophy of science, whose references to Bacon will be more closely examined later. The direct references derive primarily from *De Augmentis Scientiarum* [...],[31] while indirect reference is made once to *Historia Vitae et Mortis*[32] and to *Historia Ventorum.*[33] In certain ways, which will be more clearly spelled out below, this work can be seen as a parallel project to Bacon's *Sylva Sylvarum*.

An Overview of Further Works

The spiritual and secular instructional poems *Nathan und Jotham* appeared from 1650 to 1651. According to van Gemert, this collection of short essays attempt to convey Christian virtues and proper social behavior.[34] Among the instructional poems there are several devoted to people, including two scientists, namely Valerianus Magni (1587–1668),[35] who played an important role in research into the vacuum, and Francis Bacon.[36] As usual in this work, one page is dedicated to each theme, and Harsdöffer, in his section on Bacon, gives a summary of the construc-

[30] Ibid., vol. III, *Register der Scribenten.*

[31] Harsdörffer – Schwenter, *Deliciae Physico-Mathematicae oder Mathematische und Philosophische Erquickstunden* vol. II, 435; vol. III, 37, 43.

[32] Ibid., vol. III, 569.

[33] Ibid., vol. II, 480.

[34] Cf. Harsdörffer, *Nathan und Jotham: das ist Geistliche und Weltliche Lehrgedichte* vol. I, XXIV.

[35] Cf. Sousedík S., *Valerianus Magni 1586–1661* (Sankt Augustin: 1982); Cygan J., "Valerian Magni-Lebensdaten, Werke, Sendung" *Monumenta Guerickiana* (1992) 30–38.

[36] Harsdörffer, *Nathan und Jotham: das ist Geistliche und Weltliche Lehrgedichte* vol. I, 162.

tion of the house of Salomon from *Nova Atlantis*, which thus appears again in a prominent position.

In 1647 Endter published the *Poetische Trichter*, which went through a series of expansions and new printings in subsequent years. As might be expected, this work expressing Harsdörffer's poetic theory seldom addresses topics of natural science. Yet, in the third part of the *Poetische Trichter*, published in 1653, Harsdörffer makes renewed reference to *De Dignitate* [...] (on the necessity of writing other books) and to *De Sapientia Veterum*[37] (on the wisdom of antiquity concerning things of nature). In *Der Grosse Schau-Platz Lust- und lehrreicher Geschichte* and in *Der Grosse SchauPlatz Jämmerlicher Mordgeschichte*, Harsdörffer offers two anecdotes in which Bacon is mentioned.[38] In *Heraclitus und Democritus*, a collection of sad and humorous tales, the prologue to the second half cites the words of a famous Englishman which can also likely be attributed to Francis Bacon.[39]

The Themes of Baconian Philosophy through the Eyes of Harsdörffer

The Recovery of Paradise[40] *and Arcadian Utopia*

The question, what actually should be the goal and intention of science and its technological application, is as relevant today as it was in the 17th century. This view, however, takes for granted that it is at all worthwhile to pay attention to the earthly life of humankind. The belief that man is a "defective creature" requiring the help of civilization was already common in ancient philosophy and finds its mythological expression in the Prometheus myth. In Christianity, it is after the Fall that man becomes a needy creature who must live as best he can through toil and pain outside the original paradise. A thorough-going

[37] Harsdörffer G.P., *Poetischer Trichter*, 3 vols. (Nuremberg: 1650–1653, facs. ed. Hildesheim: 1971) vol. III, 28, 105.

[38] Harsdörffer G.P., *Der grosse Schau-Platz Lust- und Lehrreicher Geschichte*, 2 vols. (Frankfurt am Main-Hamburg: 1664) vol. I, 158 (first ed. 1649–50); Harsdörffer G.P., *Der Grosse Schau-Platz jämmerlicher Mord-Geschichte* (Hamburg: 1656) 726. First ed. 1650, revised and enlarged 1651.

[39] Harsdörffer G.P., *Heraclitus und Democritus. Gedolmetscht aus den lehrreichen Schriften H.P. Camus [...] durch ein Mitglied der hochlöblichen Fruchtbringenden Gesellschaft* (Nuremberg: 1652–1653).

[40] Cf. Harrison P., *The Bible, Protestantism, and the Rise of Natural Science* (Cambridge: 1998) 205–265.

allegorical interpretation of paradise by Augustine and Origenes must have made it seem virtually pointless to improve the life of man in the here-and-now. However, there are time and again historical interpretations of paradise whose inclusion of ancient elements lead to utopian and chiliastic thought.[41] Francis Bacon and, building on him, Harsdörffer take these as their starting point.

For Harsdörffer, the starting point and goal of natural science and technology is the perfection of paradise.[42] It is, for him, an historical fact that Adam originally had absolute knowledge, not through works but through the grace of God, and that he lived, as it were, in eternal bliss without suffering, work or death. In this respect, Harsdörffer is on common ground with those researchers who, building on the work of Paracelsus, tried to renew natural science.[43] The Fall changed man from a perfect being to one in need, and it is precisely this need which must be compensated, a point-of-view already emphasized by the mediaeval understanding of the arts.[44] Thus, the task of science is at once a process of moving ever closer to the original paradise[45] through the research of God's secrets and their practical application on material supplied by nature.[46] As Harsdörffer writes in the *Erquickstunden:*

> Diesemnach schliesse ich/daß alle gute Erfindungen anfänglich von GOtt dem Herrn/als dem Vater des Liechtes hergekommen/keiner gewiessen affterursache aber beyzumässen/sondern daß theils so/theils anderst/an das Liecht und in Gebrauch gekommen/und noch kommen können/sonderlich aber in Philosophischen und Mathematischen Sachen.[47]

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[41] Cf. Saage R., *Utopische Profile*, vol. I: *Renaissance und Reformation*, Politica et Ars. Interdisziplinäre Studien zur politischen Ideen- und Kulturgeschichte (Münster: 2001) 48–67.

[42] Cf. Stoecklein A., *Leitbilder der Technik. Biblische Tradition und technischer Fortschritt* (Munich: 1969) 36–59.

[43] Cf. J.B. van Helmont, *Aufgang der Artzney-Kunst* (Sultzbach: 1683, facs. ed. Munich 1971) 866.

[44] Stoecklein A., *Leitbilder der Technik* 40.

[45] Harsdörffer G.P., *Frauenzimmer Gesprächspiele*, 8 vols. (Nuremberg: 1641–1649) facs. ed. I. Böttcher, Deutsche Neudrucke, Reihe Barock ed. E. Trunz 13–20 (Tübingen: 1968–1969) vol. IV, 235–239 (279–283). The page numbers of the facs. ed. are given in parentheses.

[46] Harsdörffer – Schwenter, *Deliciae Physico-Mathematicae oder Mathematische und Philosophische Erquickstunden* vol. III, 158–159.

[47] Ibid., vol. III, 8.

Seen in this way, natural scientific research is at once a service to mankind, even to God himself.[48] These abilities are bound up with an aesthetic program of music and poetry serving to praise God and his creation.[49] We can agree with Klaus Conermann's conclusion that here poet and technician become the creators of a new poetical and technological world.[50]

God endowed man with the capacity for science and cognition.[51] Man is the masterpiece of God's creation and capable, as it were, of infinite understanding.[52] It is the task of human ability to complete that which nature – as the substance for all human creation – has left incomplete[53] and thereby to heal those infirmities brought about by the Fall. As Harsdörffer writes on the relationship of art, or technology, and nature:

> Die Natur soll der Kunst/und die Kunst der Natur an die Hand stehen/wie der Poët seine Erfindung dem Mahler in der Pinsel gibet/und indem diese beede ihre Kunstkinder zusammenvermählen/erweisen sie eine erbliche Verbrüderung/welche sich möglichster Vollkommenheit nähert.[54]

This process is, however, at the same time infinite, our knowledge and with it our abilities remain fragmentary.[55] Nevertheless, it also remains true that man is capable of creating nothing short of miracles; he can make the seemingly impossible – through his knowledge of nature and its practical application – possible.[56] Out of the marriage of art and nature – as Harsdörffer writes in his dedicational poem to Gaspar Schott's *Magia optica* – the machine is born.[57] In another text, Hars-

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[48] Harsdörffer, *Nathan und Jotham: das ist Geistliche und Weltliche Lehrgedichte* vol. II, 378.

[49] Harsdörffer – Schwenter, *Deliciae Physico-Mathematicae oder Mathematische und Philosophische Erquickstunden* vol. III, 623.

[50] Conermann K., "Der Poet und die Maschine. Zum Verhältnis von Literatur und Technik in der Renaissance und im Barock", in Allemann B. (ed.), *Teilnahme und Spiegelung: Festschrift für Horst Rüdiger* (Berlin: 1975) 173–192, 191.

[51] Harsdörffer – Schwenter, *Deliciae Physico-Mathematicae oder Mathematische und Philosophische Erquickstunden* vol. III, 8.

[52] Ibid., vol. II, 110–111.

[53] Ibid., vol. III, 158; vol. II, 382.

[54] Ibid., vol. III, 159.

[55] Ibid., vol. III, 346.

[56] Ibid., vol. II, 382; Francis Bacon, "Novum Organon", in Rees G. – Wakely M. (eds.), *The Oxford Francis Bacon* (Oxford: 2004) vol. XI, 55.

[57] Stöcklein A., *Leitbilder der Technik* n. 32, 120–121.

dörffer uses the machine in reference to Bacon's *Novum Organon* as a synonym for the new and certain, namely Baconian, method of natural scientific research.[58]

Bacon relates his basic goal of improving human life in the here and now[59] to this paradisiacal recovery, as he writes in the last aphorism of *Novum Organon*: '*For man, by the fall, lost at once his state of innocence, and his empire over creation, both of which can be partially recovered even in this life, the first by religion and faith, the second by the arts and sciences.*'[60] Wise, old testament King Solomon plays an important role here as model. Already in the dedication of the *Instauratio magna* to James I (1566–1625), Solomon is an advocate of science:

> Lastly, I have a request to make – a request no way unworthy of your Majesty, and which especially concerns the work in hand; namely, that you who resemble Solomon in so many things – in the gravity of your judgments, in the peacefulness of your reign, in the largeness of your heart, in the noble variety of the books which you have composed – would further follow his example in taking order for the collecting and perfecting of a Natural and Experimental History, true and severe (unincumbered with literature and book-learning), such as philosophy may be built upon – such, in fact, as I shall in its proper place describe: that so at length, after the lapse of so many ages, philosophy and the sciences may no longer float in the air, but rest on the solid foundation of experience of every kind, and the same well examined and weighed. I have provided the machine, but the stuff must be gathered from the facts of nature.[61]

In the utopian *Nova Atlantis*, to which we shall return later, the importance of Solomon is further developed. Thus, it cannot come as a surprise that the authors of the 17th-century books on machine building were familiar with Bacon and made reference to him. Not because Bacon had developed any concrete inventions, but because he propagated the ideal of worldly perfection attainable through the natural sciences and technology, as Ansgar Stoecklein concludes[62] – visions thoroughly compatible with chiliastic thought.

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[58] Harsdörffer, *Frauenzimmer Gesprächspiele* vol. I, 30 (52).

[59] Cf. Briggs J.C., "Bacon's science and religion", in Peltonen M. (ed.), *The Cambridge Companion to Bacon* (Cambridge: 1996) 172–199.

[60] Bacon, "Novum Organon" II 52, *The Oxford Francis Bacon* vol. XI, 89.

[61] Spedding J. – Ellis R.L. – Heath D.D. (eds.), *The Works of Francis Bacon* (London 1860) vol. IV, 12.

[62] Stoecklein A., *Leitbilder der Technik* 51.

Taking up Bacon's interpretation of ancient mythology yet going beyond it, of course, is Harsdörffer's addition of a utopian dimension in the form of a literary arcadia – an idea with which Harsdörffer, as virtually no other German literati, was thoroughly versed.[63] The ancient arcadia, at once an earthly variant of paradise, can be realized through human technology. Here, we are dealing not only with the satisfaction of basic needs but most certainly with luxury, just as Bacon too had imagined it in *Nova Atlantis*.[64] Already in the *Pegnesische Schäfergedicht* and its continuation, Nuremberg becomes the new site of arcadia – with its imagined fruits such as, among other things, lemons. This Nuremberg is not only a green garden. An early-industrial infrastructure of every conceivable kind of mill fills the meadows of the city's river, Pegnitz, building the backbone of the manufacturing industry. This comes to expression, not least, in Nuremberg's popular literature devoted to the mechanical arts, such as Georg Andreas Böcklers (1617–1687) *Theatrum Machinarum Novum* and Andreas Jungnickels (? –1654) *Schlüssel zur Mechanica*.[65] The mechanical arts, which we would today refer to as mechanical engineering, play a special role in Harsdörffer's work, so indebted as it is to its location. In the first half of the 17th century, Nuremberg was one of the most important economic centers of the old empire, despite the hardships it had undergone in the siege of 1632 and the great pest of 1634, to which more than 20,000 people fell victim.[66] At the time, Nuremberg was best known as a center for printing and instrument making. This tendency toward pratical technology is also evident in Harsdörffer's specialist publications.[67] Technology even made possible the introduction of mediterranean plants into Nuremberg's

[63] Harsdörffer G.P., *Pegnesisches Schaefergedicht in den berinorgischen Gefilden angestimmet von Strefon und Clajus* (Nuremberg: 1644) preface.

[64] Cf. Schaper-Rinkel P., "Technik, Wissen und Macht in Utopien und Zukunftsvorstellungen der Frühen Neuzeit", in Engel G. – Karafyllis N.C. (eds.), *Technik in der Frühen Neuzeit-Schrittmacher der europäischen Moderne, Zeitsprünge* 8, 3/4 (Frankfurt am Main: 2004) 245–259.

[65] Cf. Böckler G.A., *Theatrum Machinarum Novum* (Nuremberg: 1661); Jungnickel, A., *Schlüssel zur Mechanica* (Nuremberg: 1661).

[66] Cf. Schieber M., *Nürnberg: eine illustrierte Geschichte der Stadt* (Munich: 2000) 79–90; Endres R., "Nürnbergs Stellung im Reich im 17. Jahrhundert", in Paas J.R. (ed.), *"der Franken Rom". Nürnbergs Blützezeit in der zweiten Hälfte des 17. Jahrhunderts* (Wiesbaden: 1995) 19–45; Stromer W., "Nürnberg als Epizentrum von Erfindungen und Innovationen an der Wende vom Mittelalter zur Neuzeit", in Schachtschneider K.A. (ed.), *Wirtschaft, Gesellschaft und Staat im Umbruch* (Berlin: 1994) 668–687; Bussmann K. – Schilling H. (eds.), *War and Peace in Europe*, 3 vols. (Münster: 1998), vol. II, 347–357.

[67] Böttcher I., "Der Nürnberger Georg Philipp Harsdörffer" 292.

horticulture. All of this is evidence of the early German longing for Italy. '*Welschland*,' writes Harsdörffer, '*ist der Garten/und das irdische Paradis in Europa.*'[68] Moreover, Nuremberg had a strong humanist tradition. Harsdörffer's awareness of the new dangers introduced by technology – not least through the catastrophe of the 30 years war – is again much deeper than that of Bacon.

In a discussion in the *Gesprächspiele* about whether the invention of artillery had caused more damage than the invention of printing had brought benefits – inventions that Bacon too counts among the most exceptional achievements of humankind in the early modern period[69] – Harsdörffer reaches the conclusion:

> Wann man also den trefflichen Nutzen der Bücher/gegen den erschrecklichen und unaussprechlichen Schaden des Geschützes halten wil/wird sich befinden/daß viel tausend Menschen mehr durch diese um das Leben gebracht/als durch jene erhalten worden. Dann ob zwar auch das Geschütze zum Schutze wider allerhand Gewalthaten zu gebrauchen/so ist doch leider/Gott erbarme es/der Mißbrauch weit grösser als der Gebrauch selbsten.[70]

Scientific Progress

From the idea that the goal of science is to improve human life, i.e. to restore the lost paradise, it follows that scientific knowledge is never complete but subject to continual improvement and development, indeed, that the majority of its work has yet to be done. Already in the first part of the *Gesprächsspiele* it is clear that science is subject to this continual process of development. This is thanks, not least, to the invention of printing. There is, indeed, still much that is unknown to man, yet human understanding is capable of studying everything.[71] Here, Harsdörffer takes up a Baconian position. However, the two differ in their assessment of the initial situation: in comparison to Bacon, exactly one generation older,[72] Harsdörffer is thoroughly aware of the accomplishments of science in the first half of the 17th century. Both, however, agree that nothing can be expected from scholastic science

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[68] Harsdörffer, *Frauenzimmer Gesprächspiele* vol. II, 221 (239).
[69] Bacon, "Novum Organon" I 129, *The Oxford Francis Bacon* vol. XI, 195.
[70] Harsdörffer, *Frauenzimmer Gesprächspiele* vol. IV, 416–417 (460–461).
[71] Ibid., vol. VIII, 285 (326).
[72] Cf. Bacon, "Novum Organon" I 74, *The Oxford Francis Bacon* vol. XI, 119.

with regard to the understanding of nature. Harsdörffer writes in the second volume of the *Gesprächspiele*:

> Es wäre zu wünschen/daß die alten Schulfüchse die Wirdigkeit der Künst und Wissenschafften/mit ihrem ungeschlachten und unartigen Sitten/bey Fürstenhöfen nicht so verächtlich gemacht hätten.†Indem sie die jetzige Zeiten/mit denjenigen so sie aus vielen Büchern erlernet vergleichen/ kommet ihnen alles/welches sie in ihrer gewöhnlichen Einsambkeit nicht gesehen/noch sehen mögen/so frembd vor/daß sie sich gantz nicht in die Welt schicken/auch von allen nicht wol anderst/als ungleiche Reden führen können.[73]

The New Science of Nature

Mathematics and the Mechanical Arts

Again, Harsdörffer's concept of mathematics is much broader than modern concepts, considering 'mathematical' virtually anything having to do with quantification. This set is divided into pure and applied mathematics, whereby to the latter belong what today would be subfields of technology. Anything not fitting into one of these categories is referred to with the term *art*, which includes the entirety of human capabilities and tools for the processing of nature and is, thus, roughly analogous to our concept of technology.

In his history of learned literature, Jacob Friedrich Reimmann (1668–1743) counts Harsdörffer along with Schwenter among the most important German mathematicians. The equally universal view of mathematics can be found still more than 60 years after the publication of the *Erquickstunden* in Christian Wolff's (1679–1754) *Mathematisches Lexicon*, where he defines it above all as a science of quantification at the root of all knowledge of the natural world.[74] Reimmann includes the following fields in his concept of mathematics: arithmetic, geometry, music, optics, astronomy, chronology, geography and mechanics. A similar categorization can be seen in Zedler still in 1739, whereby here mathematics is understood as nothing less than a key scientific

[73] Harsdörffer, *Frauenzimmer Gesprächspiele* vol. II, 38–39 (56–57).

[74] Reimmann J.F., *Versuch einer Einleitung in die Historiam Literariam derer Teutschen* vol. IV, 130–32; Wolff, *Mathematisches Lexicon* 863.

discipline and instrument of domination over nature.[75] The emancipation of practical knowledge, as it had developed especially in the 16th and 17th-centuries, comes here to clear expression.

Bacon, too, shares this view of the basic division of mathematics, whereby he sees mathematics not as a subcategory of natural philosophy but of metaphysics.[76] It has frequently been remarked that Bacon did not recognize the significance of mathematics for the renovation of 17th century natural sciences, as did, for example, Galileo. Thus, he argues in *Novum Organon*:

> We have yet to find a pure natural philosophy; so far it has been infected and corrupted: in Aristotle's school by logic; in Plato's by natural theology; in Plato's second school – that of Proclus and others – by mathematics, which ought to round off natural philosophy and not generate or procreate it. But from a natural philosophy pure and quite without admixture we should hope for better things.[77]

In comparison, Harsdörffer is quite clear about the importance of mathematics. It can be assumed that this change in attitude is a reflection of developments since Galileo: 'was aber gegenwärtig mit Zahlen und Linien vor Augen lieget/das kan kein Verständiger verneinen/und beruhet in unbetrieglichem Beweisthumb,'[78] writes Harsdörffer. A remarkable number of pages in the *Erquickstunden* is thus devoted to treatments of the subject. In poetic exuberance Harsdörffer writes of mathematics:[79]

> Unendlicher Reichthum kommet durch die Arbeit ihrer Hände (vermittelst der Baukunst Wasserkunst/etc.) und viel Klugheit durch ihre Gesellschafft/(in Kunstmässiger Betrachtung der Geschöpffe GOttes) und ein guter Ruhm durch ihre Gemeinschafft und Rede.[80]

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[75] Reimmann J.F., *Versuch einer Einleitung in die Historiam Literariam derer Teutschen* vol. IV, 140; Zedler, J.H., *Grosses vollständiges Universal-Lexicon aller Wissenschafften und Künste* (Halle-Leipzig: 1739) vol. IXX, 2046–2050, especially 2048.

[76] Bacon, "The Advancement of Learning" II, *The Oxford Francis Bacon* vol. IV, 88.

[77] Bacon, "Novum Organon" I 96, *The Oxford Francis Bacon* vol. XI, 153, 155.

[78] Harsdörffer – Schwenter, *Delitiae Philosophicae et Mathematicae: der philosophischen und mathematischen Erquickstunden 3. Teil* vol. III, 17.

[79] Cf. Thiele R., "Georg Philipp Harsdörffer, der Spielende, als Mathematiker", *Acta Historica Leopoldina* 39 (2004), 267–323.

[80] Harsdörffer – Schwenter, *Deliciae Physico-Mathematicae oder Mathematische und Philosophische Erquickstunden* vol. II, dedication; cf. *Mass, Zahl und Gewicht. Mathematik als Schlüssel zu Weltverständnis und Weltbeherrschung*, Ausstellungskataloge der Herzog August Bibliothek Wolfenbüttel 60 (second edition Wolfenbüttel: 2001) 5–32.

Mathematics plays a central role in the fervent discussion of Copernican theory:

> Zu dem haben sie ihre Rechnungen/welche die Sonn- und Mondfinsternussen so genau erweisen/daß sich darüber zu verwundern/und gewißlich aus der Planeten Lauf Copernicus nicht kan widerleget werden. Die natürlichen Ursachen aber/welche Robert. à Fluctibus, und andere wider ihn anführen/können den Beweiß aus der Gestirne Rechnung nicht hindertreiben.[81]

Otherwise, the renown of mathematics is based above all on mechanical engineering, which is dealt with in the *Erquickstunden* under the heading '*Von der Waagkunst/und den gewaltsamen Bewegungen*'. The ancient distinction of natural and artificial movements, characterized by Harsdörffer as violent, is still reflected here.

> Unter diesen letzten ist auch die Mechanica die aller wundersamste/weil sie die Bewegung lehret/und in dem sie mit der Hand zu Wercke richtet/was der höchste Schöpffer mit dem allgewaltigen Wort: **Es werde**/ außgewürcket/und ist sie zu Erhaltung der Kunstgewerbe/wie jene/zu Erhaltung dieses Weltbaues/höchstnothwendig/nutzlich und erfreulich zu studiren.[82]

Mechanical engineering serves the development of marvels through which the elements become useful to people against the usual course of nature and, thus, serve to balance their weakness, namely their neediness.[83] Harsdörffer was apparently unaware of Galileo's justification of mechanics as a science in the *Discorsi* 1637. After all, this kind of detailed analysis lay outside the boundaries of his stated intentions.

For Bacon, the mechanical arts are a font of innovation, even if they are still wanting in depth and method. There is always something new happening there and thus they are placed in direct opposition to the unfruitful speculations of philosophy to date.[84] The development of the mechanical arts, like artillery, ship travel, and printing, thereby progresses from simple beginnings to ever greater perfection, while in the field of philosophy precisely the opposite occurs in that, since antiquity,

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[81] Harsdörffer – Schwenter, *Deliciae Physico-Mathematicae oder Mathematische und Philosophische Erquickstunden* vol. II, 287.
[82] Ibid., vol. III, 383.
[83] Ibid., vol. III, 383.
[84] Bacon, "Novum Organon" I 74, *The Oxford Francis Bacon* vol. XI, 119.

it has merely continued to deteriorate.[85] Bacon's goal is to build up mechanics on the grounds of practical experience, to systematize it and methodologically analyze it.[86] Only then can even further development be possible – a concern he addresses in *Nova Atlantis*.

The Pan Myth and Foundation of Natural Philosophy

In Volume IV of the *Gesprächspiele* – and introductory to his shepherds poem *Seelewig* – the myth of the Greek god Pan is told, naturally in Christian reinterpretation.[87] For Harsdörffer the interpretation of this myth yields an important connection to natural philosophy. Building on the Greek word 'Pan', he explains:

> Pan ist dieser gantze Weltbau/welcher entstanden entweder von Mercurio/das ist dem Göttlichen Wort/oder wie etliche aus ihrer Vernunft geschlossen/aus den kleinen Stäublein/welche als die erste Materie oder Gezeug mit vielerley Form vermischet gewesen.[88]

With this line of interpretation, Harsdörffer arrives effortlessly at the natural sciences, writing further of Pan:

> Er ist der Jägergott/weil alles in dieser Welt nichts anders als eine Jagt ist: alle Wissenschaften jagen mit emsiger Hoffnung nach Lust/oder nach Nutzen. Er ist der Hirten und Bauersleutgott/weil durch sie die Welt ernehret wird. Ein Herr der Berge/dieweil auf denselben die Welt fürgewiesen wird. Daß er auch der nechste nach dem Mercurio seye/ist dahin zu verstehen/daß die Welt nechst dem Wort Gottes unser bester Prediger/wie dann der Geistliche Poet und Profet singt: Die Himmel erzehlen die Ehre Gottes/und seine Hände Werke weisen das Gestirne.[89]

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[85] Bacon, "The Advancement of Learning" I, *The Oxford Francis Bacon* vol. IV, 27–28.

[86] Bacon, "Novum Organon" I 99, *The Oxford Francis Bacon* vol. XI, 157, 159.

[87] Cf. Berns J.J., "Gott und Götter. Harsdörffers Mythenkritik und der Pan-Theismus der Pegnitzschäfer unter dem Einfluß Francis Bacons" 47–81; Jürgensen R., *Utile cum dulci = Mit Nutzen erfreulich: die Blütezeit des Pegnesischen Blumenordens in Nürnberg 1644–1744* (Wiesbaden: 1994) 20–22; Schottel J.G., *Fruchtbringender Lustgarte* (Wolfenbüttel: 1647); Blume D., "Im Reich des Pan: Animistische Naturdeutung in der italienischen Renaissance", Prinz W. – Beyer A. (eds.), *Die Kunst und das Studium der Natur vom 14. zum 16. Jahrhundert* (Weinheim: 1987) 253–275; Brummer H.H., "Pan Platonicus", *Konsthistorisk Tidskrift* 33 (1964) 1–2, 55–67; Mulryan J., "Literary and Philosophical Interpretations of the Myth of Pan", *De Pétrarque à Descartes* 38 (1980) 209–218; Merivale P., *Pan the Goat-God* (Cambridge/Mass.: 1969) 1–47.

[88] Harsdörffer, *Frauenzimmer Gesprächspiele* vol. IV, 17 (61).

[89] Ibid., 19 (63).

Harsdörffer touches, here, on classical two-book doctrine, as well as the interpretation of ancient mythology through Bacon[90] and his predecessors, and opens a perspective to natural philosophy. As Jörg Jochen Berns has already shown, the degree of similarity here goes down to the finest details.

In the preface to *De sapientia veterum*, Bacon shows himself thoroughly aware of the problematic of such mythical interpretation; Harsdörffer adopts this same position, making explicit reference to Bacon.[91] Bacon – and thus Harsdörffer – feel justified in their interpretation for it gives expression to a hidden truth of which only fragments are preserved in the Bible but which must be made accessible. Even if the interpretations are not entirely accurate, they can nevertheless serve to facilitate the introduction of new knowledge.[92]

For Harsdörffer, the Pan myth provides an important connection to the arcadian utopia, as the arcadian god, Pan, together with arcadia, has in the meantime become a resident of the realm of the river Pegnitz. Jörg Jochen Berns maintains that in their enthusiasm for nature the Pegnitz shepherds mirrored and deepened to a pantheistic level the natural sciences, natural language and natural poetry in myth.[93] The grotto of Pan thus becomes, as Berns goes on to explain, a substructure of early industrial Nuremberg. That this seemingly very random early modern mythical interpretation is not an individual case, but even comes to architectural expression, becomes clear in the case of the castle of Honoré d'Urfé' – author of one of the most important European arcadian novels set in the French Forez and also known to Harsdörffer. There a grotto-like Nymphaeum in which Pan is also present serves as a vestibule to a Christian chapel.

Beyond the Pan myth, classical ancient philosophy is always present in Harsdörffer's work. While it is clear that knowledge has advanced since the time of Aristotle,[94] he is among the most cited authors who 'sich für einen Monarchen in der Philosophie aufgeworffen/der aller andrer

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90 Cf. Bacon, "De Sapientia Veterum", in Spedding J. – Ellis R.L. – Heath D.D. (eds.), *The Works of Francis Bacon* (London: 1861) vol. VI, 635–641.

91 Harsdörffer, *Frauenzimmer Gesprächspiele* vol. IV, 29 (73).

92 Cf. Schottel, "Eine neue ergetzliche Vorstellung des WaldGott Pans/samt seinen Verrichtungen […]", in Idem, *Fruchtbringender Lustgarte* 210.

93 Berns J.J., "Gott und Götter. Harsdörffers Mythenkritik und der Pan-Theismus der Pegnitzschäfer unter dem Einfluß Francis Bacons" 78.

94 Harsdörffer – Schwenter, *Delitiae Philosophicae et Mathematicae: der philosophischen und mathematischen Erquickstunden 3. Teil* vol. III, 27.

Meinungen bezwungen/und besieget.'[95] However, in the meantime, there is much that has been better studied than in antiquity, as evidenced especially in the new possibilities of astronomical calculation.

It is one of Harsdörffer's chief objectives to utilize the most modern authors. However, one misses the polemic against Aristotle, so decisive for the renovators of the sciences, especially Francis Bacon. Generally speaking, polemical overtones seldom appear in Harsdörffer's work, for they apparently stand in too great a contrast to his life motto of 'use and delight'. Thus, on this point he parted company with Bacon. Another reason might be, however, that Harsdörffer's work takes for granted the advancements in knowledge that had taken place in the first half of the 17th century. The great renovators from Copernicus to Descartes had already refuted so much of Aristotilean philosophy that a polemic on his part seemed superfluous. Aristotle had simply already been surpassed.

The New Method

The Pan myth is apparently not only an allegory for Bacon but a methodological starting point. There is no mechanical progression in the sciences; it is more like a hunt in which one often reaches unanticipated and unintentional conclusions.[96] The image of the *venatio scientiarum* is, thus, quite common in the history of science, appearing, for example, in Gregor Reisch's *Margarita Philosophica* or Johann Baptista van Helmont's work of the same title. Though methodological reflection is rare for Harsdörffer, traces of this image can also be found in his work. In his description of Pan he writes: *'daß auch in der Natur/wie in allen Regimenten/viel durch den krummen Wege zu erhalten/welches durch den gerathen nicht auszuwürken.'*[97] Yet Harsdörffer does not further develop his thoughts on this matter for the simple reason that, unlike Bacon, Hardsörffer does not see himself as a researcher. He is concerned with the presentation and application of knowledge compiled from the most current authors of his time. His presentation, thus, takes the form of a

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[95] Ibid., 25.

[96] I would like to thank Claus Zittel for bringing this to my attention. See Zittel C., "'Truth is the daughter of time'. Zum Verhältnis von Theorie der Wissenskultur, Wissensideal, Methode und Wissensordnung bei Bacon", in Detel W. (ed.), *Wissensideale und Wissenskulturen in der frühen Neuzeit* (Berlin: 2002), 213–238, 226–227. The appropriate passages from Bacon's text are cited in detail here.

[97] Harsdörffer, *Frauenzimmer Gesprächspiele* IV, 19 (63).

broad mathematical concept rather than offering a collection of research materials as does Bacon's *Sylva Sylvarum*.

The relativity of sensory perception is no argument against the possibilities for the creation of knowledge through natural science; if made conscious, this relativity can be overcome[98] – especially through experience supported by mathematical science:

> Das Ambt eines Philosophi beruhet in Erforschung der Warheit; solche macht die Mäßkunst viel beweißlicher/und unwiedersprechlicher ausfindig/als keine sonst hochberühmte Wissenschafft/dass auch der Zweiffel selbst nichts darwieder aufbringen kan.[99]

Knowledge in this case means to recognize the causes of a phenomenon.[100] But how can we attain certain knowledge? Bacon's inductive method is proferred in approval:[101]

> Etliche setzen zum Grund aller Wisssenschafften I. Das Wort Gottes. II. die Vernunft und derselben Ursachen/wie solche von Menschen Sinne mögen erdacht werden. III. Die Erfahrung und Handanlegung/in Chimischen/und anderer Arbeit. Diese wollen eines Mangel mit dem andern ersetzen und durch diese drey alles Verborgene ausfündig machen.[102]

This is an apparent reference to the Paracelsian and Rosicrucian branch of early modern natural philosophy, to which Harsdörffer was probably exposed by Johann Valentin Andreae (1586–1654). In Andreae's utopia *Christianopolis*, the chemistry laboratory plays an important role in the community.[103] The comment added at this point that there are some natural scientists who discuss natural science in accordance with the six days of creation is likely a reference to the physics of Jan Amos Comenius, with which Harsdörffer was familiar.[104] He is skeptical, however, of alchemy/chemistry; it is much more mathematics which lays the

[98] Cf. Harsdörffer, *Frauenzimmer Gesprächspiele* vol. VII, 191–193 (264–266).

[99] Harsdörffer – Schwenter, *Delitiae Philosophicae et Mathematicae: der philosophischen und mathematischen Erquickstunden 3. Teil* vol. III, 156.

[100] Harsdörffer, *Frauenzimmer Gesprächspiele* vol. III, 15 (35) with reference to Bacon, *De Dignitate et Augmentis Scientiarum* (Straßburg: 1635) 154 (book 3, chap. IV). Cf. Spedding J. – Ellis R.L. – Heath D.D. (eds.), *The Works of Francis Bacon* vol. IV, 344–365.

[101] Harsdörffer, *Frauenzimmer Gesprächspiele* vol. V, 10 (122); cf. Bacon, "Novum Organon" I 19, *The Oxford Francis Bacon* vol. XI, 71.

[102] Harsdörffer, *Frauenzimmer Gesprächspiele* vol. V, 11 (123).

[103] Andreae J.V., *Christianopolis*, ed. W. Biesterfeld (Stuttgart: 1975) 69–70.

[104] Cf. Comenius J.A., *J.A. Comenii Physicae ad lumen divinum reformatae Synopsis, Philodidacticorum et Theodidacticorum censurae exposita. Des J.A. Comenius' Entwurf der nach dem göttlichen Lichte umgestalteten Naturkunde, dem Urteile der Unterrichtsfreunde und der Gotteslehrer vorgelegt*, ed. J. Reber, 2 vols. (Giessen: 1896).

sturdiest foundation for scientific knowledge.[105] Practical application and activity are the key to the secrets of nature; the meaning and purpose of the sciences is practical use for humankind:

> Die Wissenschaften sind Güter des Verstands/und Schätze des Geists. Wie aber die Glükkseligkeit des Reichthums nicht in dem Besitz/sondern in rechtmässigem Gebrauch desselben bestehet/also ist auch nicht genug viel wissen/sondern man muß solche Wissenschaft würklich zu Nutzen bringen.[106]

This applies especially to the study of medicine, for if we do not learn to maintain our health, we are not capable of anything else.[107] Harsdörffer's *Erquickstunden* is nothing less than an experimental compendium of his time. He is concerned with observations and experiments. Here, on the one hand, a comparison can be made with Bacon's methodological approach and, on the other, with his own compendium *Sylva Sylvarum*. Because Bacon did not contribute to the concrete develoment of science with his own discoveries and experiments, his concept of experiment was called into question as well.[108] Indeed, his view of experimentation differed from his contemporary Galileo. Bacon believed he could attain new knowledge through experiment and his three-step method, while for Galileo the experiment had a falsifying character.[109] We do not find a discussion of experiment in Harsdörffer, for here, again, what had been new terrain for Bacon had in the meantime become common knowledge. The ancient differentiation of theory and practice which Bacon still had to overcome, the orientation on works and practical benefits is also for Harsdörffer the principle of all study of nature.

Harsdörffer has a different opinion, however, of experimentation in chemistry. For him, alchemy is a subfield of chemistry which had ruined its reputation with the promise of being able to create gold or the philosopher's stone. Nevertheless, it is true: 'Die Chymia oder Schmeltzkunst/hat einen so großen Nutzen in dem Menschlichen Leben/daß fast nichts treflichers kan erdacht werden.'[110] Without

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[105] Harsdörffer, *Frauenzimmer Gesprächspiele* vol. VII, 193 (266).
[106] Harsdörffer, *Frauenzimmer Gesprächspiele* vol. VIII, preface, (29–30).
[107] Harsdörffer, *Frauenzimmer Gesprächspiele* vol. VI, 126 (257).
[108] Cf. Fischer K., *Francis Bacon und seine Schule. Entwicklungsgeschichte der Erfahrungsphilosophie* (fourth edition Heidelberg: 1923) 138–145.
[109] Cf. Heidelberger M. – Thiessen S., *Natur und Erfahrung. Von der mittelalterlichen zur neuzeitlichen Naturwissenschaft*, 159–167.
[110] Harsdörffer – Schwenter, *Deliciae Physico-Mathematicae oder Mathematische und Philosophische Erquickstunden* vol. II, 558.

chemistry there can be no certainty in the study of nature.[111] Examining discussions in a given field of research at the time of the publication of the *Erquickstunden* such as the debate surrounding the existence of the vacuum – before the experiments of Otto von Guericke – it becomes clear that Harsdörffer was well acquainted with the state of knowledge in his time. It has become a matter of course, no longer under debate, that the decision pro et contra is made on the basis of the evaluation of experiments.[112]

The House of Salomon

In volume seven of the 1647 edition of the *Gesprächspiele*, Harsdörffer, building on the discussion of the instructional poems, devotes more than twenty pages to a discussion of the house of Salomon in Bacon's utopia *Nova Atlantis*.[113] Considering, as well, the compilated texts of the *Gesprächspiele*, the *Erquickstunden* and *Nathan und Jotham*, this is by far the most detailed presentation and discussion of another author. In volume one of the 1650/51edition of *Nathan und Jotham*, Harsdörffer again provides a one-page summary. Beyond that there are individual references to Bacon's utopia scattered throughout his work. The number of references alone underscores the special meaning of this work for Harsdörffer.

In volume seven of the *Gesprächspiele*, the discussion of *Nova Atlantis* is introduced with a commentary on the books of the *'Chimisten'*, whose forms of expression, he maintains, are so opaque that one hardly knows what they are talking about – a critique frequently voiced by Bacon as well.[114] As an example, Harsdörffer cites, among others, the *'Chimische Hochzeit Christian Rosencreutzers'*.[115] In contrast, he praises the clarity of Bacon's writing, whose house of Salomon is designed after the seven days of creation. This plan was to be realized in England, but

[111] Ibid.

[112] Cf. ibid., vol. II, 465–483 and vol. III, 448–497.

[113] Cf. Grafton A., "Where was Salomon's House?": ecclesiastical history and the intellectual origins of Bacon's 'New Atlantis', in Jaumann H. (ed.), *Die europäische Gelehrtenrepublik im Zeitalter des Konfessionalismus*, Wolfenbütteler Forschungen 96 (Wiesbaden: 2001) 21–38; Kiernan M., "Introduction", in *The Oxford Francis Bacon* vol. IV, XXXVIII–LVI.

[114] Harsdörffer, *Frauenzimmer Gesprächspiele* VII, 187 (260).

[115] Cf. Bacon, "Novum Organon" I 54, *The Oxford Francis Bacon* vol. XI, 89; ibid., I 64, p. 101; ibid., I 73, p. 117.

the civil war made it impossible.[116] Harsdörffer describes his objective as '*die endliche Erkundigung aller natürlichen Ursachen/so weit es nemlich menschlicher Verstand bringen kan* [. . .]'.[117] Yet, rather than providing a simple summary, Harsdörffer moves on to a discussion of the foundation of natural science altogether.

It is first determined that there are three types of causes: supernatural, natural and artificial. Many natural causes are unknown to us, yet can still be researched. The naming of the house of Salomon is, in accordance with Bacon's own justification, traced back to the wise king's knowledge of the natural world. While the purpose of the Bible is not to explain natural causes, the knowledge of natural phenomena contained therein is nevertheless as true as the matters of faith it expresses. However, the opinion is held by many that all knowledge outside of the Bible is uncertain. Thus, the next issue addressed is the question whether there is absolute truth in the (natural) sciences. Human sense and reason are often erroneous and easily fooled. Knowledge, however, means – as it does for Bacon – knowledge of the causes of a natural phenomenon.[118] We are perfectly capable of subjecting sensory impressions to critical analysis in order to correct them and thereby attain certain knowledge. Mathematics, the art of measurement and logic can yield incontrovertible truths. Some claim, however, that these sciences can only explain phenomena without clarifying their causes, which is the actual turning point of science.[119] All the same, all causes can in principle be explained; what now remains unknown can be researched in the future.

After this scientific and epistemological introduction, founded chiefly on Bacon's arguments, Harsdörffer turns not only, as one might expect, to a description of the equipment and facilities of the house of Salomon, but to a description of the creation itself. The subsequent report is embellished with details of the construction, as well as poetic imagery not found in Bacon's text. On the door of the house stand two Tuscan pillars, framing pictures of heaven and earth. This is perhaps a reminder of the famous frontispiece of the 1620 edition of *Instauratio*

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[116] It is not entirely clear what Harsdörffer is referring to here. It is possible that he knew of the efforts of the Hartlib circle as a result of his correspondence with Comenius. Cf. Webster C., *The Great Instauration. Science, Medicine and Reform 1626–1660*, Studies in the History of Medicine 3 (Oxford et al.: 2002) 44–51.

[117] Harsdörffer, *Frauenzimmer Gesprächspiele* vol. VII, 188 (261).

[118] Cf. Bacon, "Novum Organon" I 3, *The Oxford Francis Bacon* vol. XI, 65.

[119] Cf. ibid., I 119, p. 179.

magna. Natural science is compared with a light in the dark. Because Bacon, too, depicts the house of Salomon as a college of the six days' work, Harsdörffer's discussion of the house likewise coincides with the six days of creation and thus turns first to light and therewith to the optical works and materials. Galileo's discovery of Jupiter's moon and the invention of the telescope are also mentioned. Underscored through a mechanical model – remarkably reminiscent of explanatory models in Descartes' *Principia* – some aspects of reflection and refraction are explained using simple sketches. Naturally, Harsdörffer does not want to go into too great a detail; after all, his *Gesprächspiele* and the *Erquickstunden*, both, are intended for recreational reading. The second day of creation with the division of land, water, and air is associated with the art of distillation, namely chemistry, whose possibilities and limitations are subjected to a realistic evaluation. The third day is devoted to field and garden work with the introduction of a passage from Bacon's essays and the discussion of several botanical concerns. The fourth day is devoted to astronomy. 'Unter allen Wissenschaften/,' writes Harsdörffer, 'scheinet diese die allerübertrefflichste zu seyn/indem sie nicht irdisch/sondern himmlische Sachen behandelt.'[120] Nevertheless, he goes on to deal with questions such as the benefits of certain seasons for human health. The fifth day is devoted to the mechanical water arts, ship and port construction and the animals and plants of the sea, additionally the relationship of water and air is examined. The sixth day is devoted to the animals and people. After a short commentary on vivisection, he closes with the typical conclusion, one should leave such difficult questions to the learned. A commentary on the merits of women compared to men and the question of whether the world is aging closes the chapter. The discussion of Salomon's house ends with the comment that the seventh day of creation, the day of rest, is not to be expected on earth. Entire books could be written about each day of creation and the phenomena of art and nature associated with each – again, resonances of Baconian arguments.

So much on this short summary of Harsdörffer's vision of the house of Salomon which interprets Bacon's utopia in its own unique way: 'Ein Weltmann, dabei ein letzter Reichsstädter, schreibt für gebildete

[120] Harsdörffer, *Frauenzimmer Gesprächspiele* vol. VII, 228 (302).

Kreise.'[121] This assessment, which one could say of the *Gesprächspiele* in general, defines also this presentation of Salomon's house. Harsdörffer does not want to exhaust; he takes his reader into consideration. Difficult and too in-depth material is left out, variety and entertainment are his goal. Thereby, science is taken up in the poetic and aesthetic reflection of nature and humankind. It is about a learned game at an advanced level for which the entire intellectual sphere is mobilized. Only on the basis of these prerequisites can his Bacon interpretation be understood. We can pluck out of this 'game' Harsdörffer's serious stance regarding questions of epistemology and natural philosophy.

The Influence of Harsdörffer's Bacon Interpretation

Doubtless, Harsdörffer's enthusiasm for Bacon had consequences. Firstly, it must be said that the reception of Bacon, as well as Harsdörffer, in German philosophy and science of the second half of the 17th century requires further research.[122] Not to mention the special problem of the influence of Harsdörffer's intepretation of Bacon. Questions regarding the channels through which Harsdörffer learned of Bacon, likewise, remain open. Aside from his stay in England, his epistolary relationship to Jan Amos Comenius likely plays an important role here. Comenius especially appreciated the *Erquickstunden*.[123] For the spread of Bacon's ideas in the second half of the 17th century, this work holds special significance as it appeared in numerous editions until 1692, thus stands out among Harsdörffer's other works. This, as the aforementioned citation from Tschirnhaus suggests, must be seen in the context of the scientific revolution. Any further examination of Bacon's influence would

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[121] Ed. K. Wolfskehl, *Sammlung Victor Manheimer. Deutsche Barockliteratur von Opitz bis Brockes* (München: 1927, repr. Hildesheim: 1966) 35–37; cited in G. van Gemert (ed.), *Nathan und Jotham* vol. I, IX.

[122] Cf. Klein J., "The Reception of Francis Bacon in 17th Century German Philosophy", *Intellectual News* 14 (2004) 75–93; Waterhouse G., *The Literary Relations of England and Germany in the Seventeenth Century*; Minkowski H., "Bacons Neu-Atlantis und die Vorgeschichte der Leopoldina-Carolina" 283–295; id.: "Die geistesgeschichtliche und die literarische Nachfolge der Neu-Atlantis des Francis Bacon" 120–139, 185–200; Berns J.J., "Einleitung", in Harsdörffer – Schwenter, *Deliciae Physico-Mathematicae oder Mathematische und Philosophische Erquickstunden* vol. I, XXV–XXXVII; Gerber G., "Die Beziehungen Leibniz' zu Francis Bacon", *Wissenschaftliche Annalen* 5 (1956) 4, 275–282.

[123] Michel G. – Beer J., *Johann Amos Comenius. Leben, Werk und Wirken. Autobiographische Texte und Notizen* (Sankt Augustin: 1992) 147–149, 149.

benefit greatly from an analysis of other similarly conceived works of the second half of the 17th century for traces of his thought.

The aforementioned 1654 translation of Bacon's works with short contributions from Harsdörffer must also be named here. Another interesting question for the history of influence of Harsdörffer's popularization concerns the prehistory of the *Leopoldina* as the oldest natural scientific society, still in existence today.[124] To what extent the ideas of Bacon and Harsdörffer prompted the actual founding fathers cannot be answered here. Hermann Minkowski already addressed this question in 1936. Unfortunately, the hand-written call for the founding of the society by the Schweinfurt medical doctor Johann Laurentius Bausch (1605–1665) was only recently discovered and hence remained unknown to Minkowski.[125] The goal of the society is, firstly, to create an encyclopedia of remedies for the benefit of all, a goal which can only be achieved through the collaborative work of the society, since the volume of unknown natural phenomena is so great. This encyclopedia was to take the form of monographs devoted to individual remedies. The approach is thoroughly in line with Bacon's ideas, which are particularly well-suited to a project of this sort. Harsdörffer repeatedly remarks that Bacon had called for the writing of individual works for each natural phenomenon. Minkowski points to the influence of Bacon on the older historians of the society, among others Johann Georg Volckamer (1616–1693), who lived in Nuremberg from 1642 and assumed leadership of the society in 1683.[126] Aside from the practice of medicine, Volckamer had various interests, for physics, sundials – one of Harsdörffer's hobbyhorses[127] – and numismatics. There is

[124] R. Toellner, however, contends 'daß die Gründung und Bedeutung der *Accademia Naturae Curiosorum* ein blinder Fleck im Bewußtsein der historischen Wissenschaften in Deutschland geblieben ist.' Toellner R., "Im Hain des Academos auf die Natur wißbegierig sein: Vier Ärzte der Freien Reichsstadt Schweinfurt gründen die *Academia Naturae Curiosorum*", in Parthier B. – Engelhardt D. von (eds.), *350 Jahre Leopoldina – Anspruch und Wirklichkeit. Festschrift der Deutschen Akademie der Naturforscher Leopoldina 1652–2002* (Halle: 2002) 15–43, 24.

[125] Cf. Müller U., "Die Leopoldina unter den Präsidenten Bausch, Fehr und Volkkamer (1652–1693)", ibid., 45–93.

[126] *Allgemeine Deutsche Biographie*, ed. Historische Commission bei der Königlichen Akademie der Wissenschaften (Leipzig: 1896) vol. XL, 225–226; Jöcher C.G., *Allgemeines Gelehrten-Lexikon* (Leipzig: 1751) vol. IV, 1700–1701; Günther S., "Der Nürnberger Naturforscher Johann Georg Volckamer der Aeltere", *Altes und Neues aus dem Pegnesischen Blumenorden* 3 (1897) 141–161.

[127] Cf. Harsdörffer – Schwenter, *Delitiae Philosophicae et Mathematicae: der philosophischen und mathematischen Erquickstunden 3. Teil* vol. III, 319–341 and Ritter F., *Speculum*

little doubt that Volckamer knew Harsdörffer and, given his fields of interest, was aware of his extensive publications. In his 1683 history of the academy entitled *S.R.I. Academiae Naturae Curiosorum Ortus Leges Catalogus*,[128] he makes direct reference to Bacon's *Nova Atlantis*. Already in the 1660s, the evolution of the society became more progressive under the influence of the Royal Society. In 1671, the second volume of the academy journal, the first medical and natural scientific journal worldwide, contains a continuation of the history of the academy, prefaced by a detailed acknowledgment of the Royal Society with reference to Bacon.[129] Already we can see, then, the conceptual relationship between *Leopoldina*, the Royal Society and Bacon's program. As a result of Volckamer's presidency the printing location of the journal was moved to Nuremberg, a further indication for the special position of the city. Further research on the academy's history, of the journal and the correspondence of its members could offer greater insight to Harsdörffer's contribution.

Leibniz, who in many ways takes up, summarizes and extends German scientific development at the end of the 17th century, was familiar with Harsdörffer's work and picks up the thread of his combinatorics. While there are, indeed, individual mentions of Bacon, his demands regarding the organization of the sciences had, in the meantime, become generally accepted and reverberate in Leibniz' foundation of the Berlin Academy of Sciences.

Solis, Das ist: Sonnen-Spiegel/Oder Kunstständiger/leichter und grundrichtiger Bericht von den Sonnen Uhren (Nuremberg: 1652). According to Dünnhaupt G., *Personalbibliographien zu den Drucken des Barock* (Stuttgart: 1991) vol. III, 2011 this is a newly revised and anonymous edition of the original three part text by F. Ritter in 1607, with the third part stemming entirely from Harsdörffer.

128 Volckamer J.G., *S.R.I. Academiae Naturae Curiosorum Ortus Leges Catalogus* (Nuremberg: 1683).

129 Müller U., "Die Leopoldina unter den Präsidenten Bausch, Fehr und Volckamer (1652–1693)" 61.

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FORMAL CAUSES AND MECHANICAL CAUSES: THE ANALOGY OF THE MUSICAL INSTRUMENT IN LATE SEVENTEENTH-CENTURY NATURAL PHILOSOPHY

Benjamin Wardhaugh

This paper is concerned with the uses that could be made of the idea of 'harmony' and the analogy of the musical instrument in natural philosophy in late seventeenth-century England. It deals in particular with the diversity of those uses, which illustrates a shift between two quite different understandings of the meaning of a musical analogy. This research arises from my doctoral work on 'Mathematical and mechanical studies of music in late seventeenth-century England', and the reader is referred to my doctoral thesis for a fuller account of the sources and context for this paper. There I show how the diversity of uses of 'harmony' can illuminate the mechanical, mathematical, and experimental approaches to sound and music which we find in this period.[1] The concepts of harmony and, in a mechanical context, harmonious vibration, could have very wide application, and it is not possible to do more here than to display some illustrative examples.

Newton: Harmony as Formal Cause

A well-known example of the use of harmony in natural philosophy is that by Isaac Newton. He asserted that the spectrum produced by a prism was most naturally divided up into seven regions whose relative sizes corresponded to the harmonious division of the musical string: the spectrum 'was divided in about the same proportion that a String is, between the end & the midle, to Sound the tones in an eight [i.e. an octave].' If *xy* is the length of the spectrum,

[1] Wardhaugh B., "*Mathematical and Mechanical Studies of Music in Late Seventeenth-Century England*" (unpublished D.Phil thesis, Oxford: 2006) especially 246–262.

> *xz* the length of a Musical String double to *xy*, & divided between *x* & *y*, so as to sound the tones [. . .] [Take] *xH* the half, *xG* & *GI* the third part, *yK* the fift part, *yM* the eighth part, & *GE* the ninth part of *xy* [. . .] and the intervals between these divisions express the spaces which the colours [. . .] took up, every colour being most briskly specific in the midle of those spaces.[2]

He also displayed a circular diagram in his *Opticks* in connection with this correlation between colours of the spectrum and notes of the scale. There the seven basic colours were arranged around the edge of a disc, and the reader was supposed to be able to predict the result of mixing two or more colours by finding the geometric midpoint of the corresponding set of positions on the disc.[3]

In its implications about light, this 'colour wheel' was a curious device, since by bending the spectrum round into a circle it tacitly recognised the human eye's perception of nonspectral colours between red and violet. But its implicit representation of pitch was also puzzling. The amount of space occupied by each of the seven colours was determined, as Newton explained, by the correlation with the notes of the scale. The representation of pitch was somewhat more abstract here than in the initial correlation of notes with colours, in which a clear analogy was being made between the linear spectrum and the musical string, and the division of one was simply being imposed onto the other. In the circular diagram no part of a musical instrument was represented. The mathematical details of how the pitches were placed around the scale in fact brought this representation of musical pitch closer to that provided by a harpsichord's or a piano's keyboard: equal musical intervals (such as the octave) had equal sizes wherever they appeared around the circle.[4] There were also errors in the circular diagram, which varied from edition to edition of the *Opticks*, and have caused confusion for some commentators.[5]

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[2] Isaac Newton, *The Correspondence of Isaac Newton*, ed. H.W. Turnbull (Cambridge: 1959–77) I, 377: Newton to Oldenburg, 7 December 1675. More elaborate explanations are given in 'Optica', Part II, lecture 11, in Isaac Newton, *The Optical Papers of Isaac Newton*, I: *Optical Lectures, 1670–1672*, ed. A.E. Shapiro (Cambridge: 1984) 539–547 and Isaac Newton, *Opticks: or, a treatise of the reflections, refractions, inflexions and colours of light* (London: 1704) Bk. I, Pt. II, Prop. III, Expt. VII.

[3] Isaac Newton, *Opticks* I, 114 with I, part ii, plate iii.

[4] See Wardhaugh B., "Mathematical and Mechanical Studies" 80–109.

[5] E.g. Sepper D.L., *Newton's Optical Writings: a guided study* (New Brunswick, N.J.: 1994) 207.

In the version of this material in the 'Optica' (effectively an early draft of *Opticks*) Newton admitted there was some room for manoeuvre in the exact division of the spectrum:

> I could not, however, so precisely observe and define this without being compelled to admit that it could perhaps be constituted somewhat differently. For instance, if between XZ and YZ one takes eleven mean proportionals [...] this distribution of the image will also seem to fit the colors' expanses sufficiently well.[6]

To take 'eleven mean proportionals' is to realise equal temperament on the musical string, dividing the octave into twelve equal intervals. In the 'Optica' Newton gave the corresponding string lengths numerically for this division and for the original one, as on a string of length 360 units. This numerical information hints that the use of the musical analogy employed here originated in Newton's 1665 manuscript work on the division of the musical string, where equivalent divisions of a string of length 720 units were given.[7] On the other hand, there is nothing in 'Optica' or *Opticks* to suggest that Newton had done new work on music itself since those manuscripts of 1665.

In all of these cases – perhaps more obviously in the more abstract representation of pitch in the colour wheel – it was asserted that the mathematical structures of music, however they were expressed or represented, could serve to organise non-musical phenomena.

It is not hard to find precedents for such a use of music in natural philosophy. The most obvious are the various more or less sophisticated discussions of the harmony of the spheres: for example, Johannes Kepler's very elaborate cosmology in *Harmonices mundi* in 1619, where musical ratios were used for various purposes of organisation, including to organise the data arising from the relative maximum and minimum angular motions of the various planets.[8]

A similar example from later in the seventeenth century is found in a practical treatise about music by the English music teacher Christopher Simpson. Simpson gave a circular diagram showing a correlation between musical ratios, geometrical constructions and astrological

[6] Newton, *Optical Papers* 545.

[7] Cambridge, University Library, Add. MS 4000, ff. 104r–113v and Add. MS 3958 (B), f. 31r: Isaac Newton, musical calculations. See Wardhaugh B., "Mathematical and Mechanical Studies" 103–7.

[8] Johannes Kepler, *Harmonices mundi libri quinque* (Linz: 1619).

aspects, which owed a good deal to Kepler.[9] There are many other examples of the use of musical ratios to explain the structure of the heavens, including that of the English astrologer Christopher Heydon (published in 1650 but written around 1610) and a section in Pierre Gassendi's 1649 'Physica'.[10]

A more wide-ranging use of harmony was that of Marin Mersenne, writing on the subject between 1624 and 1648. His musical writings could be described as a multi-volume encyclopaedia structured around music: music was used both to organise the relationships between the different arts and sciences as well as the data of each.[11] Peter Dear has elucidated how Mersenne was fundamentally committed to locating harmonious relationships rather generally in the physical world, placing him in a theological tradition which included Augustine and Aquinas, and in which the harmony placed in the external world by its Creator bore a unique and potentially knowable relationship with the harmony likewise placed in the human person.[12]

All of these examples are earlier than Newton, and in fact Newton's use of harmony seems to have been one of the last of its kind. The only successor to it of which I am aware is a 'colour wheel', clearly modelled on Newton's, in the 1715 work on perspective by the English mathematician Brook Taylor.[13]

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[9] Christopher Simpson, *The Division Violist: or an introduction to the playing upon a ground, divided into two parts* (second edition London: 1667) 25, reproduced in Gouk P.M., *Music, Science and Natural Magic in Seventeenth-Century England* (New Haven–London: 1999) 152.

[10] Christopher Heydon, *An Astrological Discourse with mathematical demonstrations proving the powerful and harmonical influence of the planets and fixed stars upon elementary bodies in justification of the validity of astrology* (London: 1650); Pierre Gassendi, *Syntagma philosophiae Epicuri* (The Hague: 1649) II, 'Physica', sectio II Liber II caput IV: 'Quibus Intervallis Sidera a Terra, ac inter se dissita sint; et exindene, aut qualis creetur Harmonia?', in *Opera omnia* I, 560–71.

[11] E.g. Marin Mersenne, *Harmonicorum instrumentorum libri quattuor* (Paris: 1636); Mersenne M., *Harmonicorum libri* (Paris: 1636); Marin Mersenne, *Harmonie universelle contenant la theorie et la pratique de la musique, où il est traité de la nature des sons et des mouvemens, des consonances, des dissonances, des genres, des modes, de la composition, de la voix, des chants, et de toutes sortes d'instrumens harmoniques* (Paris: 1636; facs. ed. Paris: 1963).

[12] Dear P., *Mersenne and the Learning of the Schools* (Ithaca, N.Y.: 1988) especially 96–169. On the related issue of the 'spiritual hearing' of the psalms and their interpreters see Sears E., "The Iconography of Auditory Perception in the Early Middle Ages: on psalm illustration and psalm exegesis', in Burnett C.F. – Fend M. – Gouk P.M. (eds.), *The Second Sense: Studies in hearing and musical judgement from antiquity to the seventeenth century* (London: 1991) 19–42.

[13] Brook Taylor, *New Principles of Linear Perspective* (London: 1719) 62–70 with fig. 25. Facsimile edition in Anderson K., *Brook Taylor's Work on Linear Perspective* (London: 1992) 145–243: see 222–230 and 243; see also Anderson's discussion at 48–51.

I use the term 'formal cause' for these uses of music. It is not a term I have found in the sources, but it is a useful shorthand, and one which might well have been acceptable to the historical actors in question. Aristotle's four kinds of causation were material, formal, efficient, and final: roughly speaking the material cause is the substance that constitutes a thing; the formal cause is the pattern or blueprint determining its form; the efficient cause is the agency producing it; and the final cause is that for the sake of which it is produced, the end towards which the production is directed. What I have discussed in the case of Newton and others are cases where music is taken to determine the form taken by some other phenomenon: that is, music provides a formal cause.

Hooke, Boyle, and Others: Harmony as Analogy for Efficient Causes

Mechanical Causes

A rather different use of music is to be found in the natural philosophy of Robert Hooke: he used it as a source of mechanical analogies. In the Aristotelian terminology introduced above, Hooke used music to provide models for efficient (and specifically mechanical) causes.

Hooke and others attached importance to the phenomenon of sympathetic resonance. (This is, in general, the tendency of a body to vibrate if another body tuned to the same pitch sounds nearby. Examples are the vibration of a violin while another is being played nearby, or the vibration of a wine glass when a particular pitch is sung near it. In the seventeenth century, the canonical example was that if two strings were tuned to the same note and one of them was struck or bowed, the other would visibly vibrate.) Hooke used sympathetic resonance as an explanation of mechanical effects in various writings, including *Micrographia* (1665):

> I suppose the *pulse* of heat to *agitate* the small parcels of matter, and those that are of a *like bigness*, and *figure*, and *matter*, will *hold*, or *dance* together [...] particles that are all *similar*, will, like so many *equal musical strings equally stretcht*, vibrate together in a kind of *Harmony* or *unison*.[14]

[14] Robert Hooke, *Micrographia* (London: 1665) 15.

In *De potentia restutiva* (1678), Hooke gave a musical analogy in more detail:

> Suppose a number of musical strings, as A B C D E, *&c*. tuned to certain tones, and a like number of other strings, as *a, b, c, d, e*, &c. tuned to the same sounds respectively, A shall be receptive of the motion of *a*, but not of that of *b*, *c*, nor *d*; in like manner B shall be receptive of the motion of *b*, but not of the motion of *a*, *c* or *d*. And so of the rest. This is that which I call *Congruity* and *Incongruity*.[15]

In these and other writings, we can see Hooke developing his idea of 'congruity': he believed that a wide range of phenomena could be explained by appealing to the vibrations of very small particles and the harmonious relationships between those vibrations.

For example, Hooke also appealed to the notion of sympathetic vibration in his attempt to explain human memory.[16] He explained the storage and retrieval of memories by envisaging a vast set of resonators in the brain: when a new sensation was received those memories in harmony with it would be reactivated by resonance.

Hooke also performed experiments with vibrating glasses, which he believed displayed vibration as a possible mechanical cause of gravity. When the experiment was performed for the final time, in March 1682/3, he described it thus:

> The Experiment was very considerable, though plain, giving a further Explanation of Gravity, by making a large Glass vibrate, with a Viol Bow: By which Vibration, a Certain Undulation is plainly seen to dart from all such Places where the Glass vibrates. And it was very plainly visible, that the Water, and Bodies in it, did move towards every such vibrating Part, and from every other Part that was at rest.[17]

And 'Mr. Hooke mentioned, that he thought, that it might contribute to explain the cause of gravity, and suggest an hypothesis for explaining the motion of gravity by'.[18] It is interesting that here the musical instrument was present not just abstractly, as the source of an analogy,

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[15] Robert Hooke, *Lectures de potentia restutiva* (London: 1678) 340–341.

[16] Robert Hooke, "An Hypothetical Explication of Memory; how the Organs made use of by the Mind in its Operation may be Mechanically understood" (Waller's title), in "Lectures of Light" VII, in Robert Hooke, *The Posthumous Works of Robert Hooke*, ed. R. Waller (London: 1705) 138–148.

[17] Robert Hooke, *Philosophical Experiments and Observations of the Late Eminent Dr Robert Hooke*, ed. W. Derham (London: 1726) 88. Cf. Birch T., *A History of the Royal Society of London* (London: 1756–7) IV, 194.

[18] Birch T., *History* II, 471.

but as a physical part of the experiment: the glass was made to vibrate by stroking it with a viol bow.

Hooke elsewhere suggested, in more general cosmological speculations, that vibrations of the earth could have attractive power even at 'a vast distance'.[19] His diary contains a cryptic hint about 'the way of the sounding of a bell by the similitude of a wheel moved upon a point like a top and [...] the severall motions of the Moon explainable thereby'.[20] I am not sure whether he thought the vibrative attraction of gravity was the same force that kept the moon in its orbit around the earth (and even the planets in theirs around the sun): from these sources this seems possible but by no means certain.

On the same occasion, Hooke displayed a conical pendulum as a model for the motion of a planet in an ellipse around the sun. Various people, including Christiaan Huygens and Christopher Wren, were working on the mathematics of pendulums at this time, and in 1687 Newton's proofs about the effects of inverse square and linear force laws would incidentally establish that the conical pendulum was a surprisingly good model for a planet moving under gravity.[21] The juxtaposition of gravity-as-vibration and the conical pendulum model in Hooke's case suggests a connection with Jeremiah Horrocks (1617–1641), the English astronomer and follower of Kepler most often remembered for being the first person deliberately to observe a transit of Venus.

In *Harmonices mundi* (1619) Kepler had suggested the planets were kept in their orbits and swept along them by magnetic fibres extending from the sun. By 1637 Horrocks, one of the few English readers of *Harmonices*, had rejected the magnetic fibres and 'set about devising his own explanation, using the conical pendulum as a model.'[22]

Horrocks also developed the analogy of harmonious vibration for the cause of the planets' motion, based on

> the wonderful experiment of musical strings: a string being struck, another string not struck is drawn with it into motion and sound, if its tension is consonant with it. The tension being dissonant, it remains still. But this sound is very small, and is not perceptible unless you place the sound of

[19] Robert Hooke, *Posthumous Works* 74–5.

[20] Robert Hooke, *The Diary of Robert Hooke 1672–1680*, H. Robinson – W. Adams (eds.), (London: 1935, 1968) 209: 8 January 1675/6.

[21] Isaac Newton, *Philosophiae naturalis principia mathematica* (London: 1687) I, § VIII.

[22] Wilson C., *Astronomy from Kepler to Newton* (London: 1989) § VI, 91, referring to Cambridge, University Library, RGO 1/68 (previously Flamsteed MSS lxviii, lxxvi) book B, Pt I: Horrocks J., "Philosophical Exercises" (etc.) ff. 71v–73v.

> the struck string afar. Indeed, the finger striking it puts into the struck string a much larger sound than that string is able to transmit to that harmoniously stretched. Why therefore should it be improbable that the same is also able to happen in the universe (which God uses as an organ for his music)? Clearly as one of the planets moves harmonically, also the motion of another is helped a little. But nothing is said concerning the motion which it receives from the sun, which, like the finger on a musical instrument, brings about a particular motion: but perhaps they give one another a certain assisting motion.[23]

And he suggested that the sizes of the planets were in inverse proportion to their distances from the sun, so that from the sun they would all appear the same size: because of its expression in ratios he called this, too, a 'harmonic' argument.[24]

The Royal Society took responsibility for publishing Horrocks' *Opera posthuma*, and his manuscripts also circulated quite widely from the late 1650s until their publication in 1672.[25] The similarity is striking with Hooke's suggestion that the conical pendulum and the phenomenon of sympathetic resonance could help to explain both the motion of the planets and gravity. Hooke does not ever seem to have acknowledged Horrocks as a source for these ideas, though.

Various other natural philosophers of this period used harmony in their mechanical explanations. An example is the English anatomist Thomas Willis, whose use of the metaphor of a musical instrument for various parts of the human body has been the subject of some attention.[26] Musical metaphors are indeed common in Willis's work,

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[23] Jeremiah Horrocks, *Opera posthuma* (London: 1673) 11: '[...] ab experimento mirabili in Chordis musicis: Chorda pulsata, Chordam aliam non pulsatam, secum in motum & sonitum trahit, si tensa fuerit sibi consone; dissone tensam, immotam relinquit. Est autem sonitus hic, exiguus admodum; neque perceptibilis, nisi sonitum chordae pulsatae illico sistas. Digitus enim percutiens, longe majorem sonitum chordae pulsatae indit, quam illa ad Harmonice tensam transmittere potest. Cur ideo non probabile erit, idem quoque in Mundo (quo Organo Deus suam exercet Musicam) posse contingere? Nempe ut unius Planetae motus Harmonicus, etiam alterius motum paulo adjuvet; nihil tamen fere, respectu Motus quem a Sole recipit; qui, quasi digitus in Organo Musico, motum praecipium illis conciliat; auxiliarem tamen aliquem Motum sibi incivem fortasse debentibus.'

[24] Wilson C., *Astronomy from Kepler to Newton* 257.

[25] Applebaum W., "Horrocks, Jeremiah", in C.C. Gillispie (ed.), *Dictionary of Scientific Biography* (New York: 1970–1980).

[26] Gouk P.M., "Raising Spirits and Restoring Souls: Early modern medical explanations for music's effects", in Erlmann V. (ed.), *Hearing Cultures: Essays on sound, listening and modernity* (Oxford: 2004) 87–105; Kassler J.C., "Man – a Musical Instrument: Models of the brain and mental functioning before the computer", *History of Science* 22 (1984) 59–82.

and he certainly believed the action of the nerves could be described by likening them to the strings of a lute. This explained the ability of one nerve to carry several different impulses, such as heat or cold.[27] The notion of congruity or 'proportionateness', possibly proportionate motion, occurred when he wanted to explain how each sense organ admitted particles bearing a certain type of sensory information but rejected others.[28] This notion of 'congruity' as a kind of proportionate vibration is very similar to what we find in Robert Hooke.[29]

In 1682 William Briggs (c. 1650–1704), another English anatomist, published a 'Theory of vision' in the *Philosophical Collections*, in which he suggested that the nerve signals from the two eyes were combined by a process analogous to the harmonising of two sounds. He says that the two fibres

> exactly answer one another in si[z]e and tension; so that when any impression from an object without, moves both Fibres, it causes not a double sensation no more than Unisons in two Viols struck together cause a double sound[.][30]

Newton himself at one stage considered the possibility that light was a vibration of the aether:

> There are pipes fill'd with a pure transparent liquor passing from the ey to the sensorium & the vibrating motion of the aether will of necessity run along thither. For nothing interrupts that motion but reflecting surfaces, & therefore also that motion cannot stray through the reflecting surfaces of the pipe but must run along (like a sound in a trunk) intire to the sensorium [...] And that vision bee thus made is very conformable to the sense of hearing which is made by like vibrations.[31]

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[27] Thomas Willis, *De anima brutorum quae hominis vitalis ac sensativa est, exercitationes duae* (Oxford: 1672), trans. S. Pordage as *Two Discourses Concerning the Soul of Brutes* (London: 1683) 61.

[28] Ibid. 54–5.

[29] Robert Hooke, *Micrographia*. Jamie Kassler finds similar ideas in the thought of Hobbes and of Roger North, although this seems less easily established from the texts than in the case of Willis. See Kassler J.C., *Inner music: Hobbes, Hooke and North on internal character* (London: 1995).

[30] Briggs W., "Theory of Vision", *Philosophical Collections* 6 (1682) 167–178 with fig. 1, at 169.

[31] McGuire J.E. – Tamny M., *Certain Philosophical Questions: Newton's Trinity Notebook* (Cambridge: 1983) 253, 488, quoting Cambridge, University Library, Add. MS 3975, f. 20.

Newton was, on the whole, favourable to Briggs' work and supported its republication in Latin.[32] But he seems to have been dubious about Briggs' specific idea, cited above, and even wrote to Briggs to criticize it:

> Disputable seems your notion about every pair of fellow fibres being unisons to one another, discords to ye rest, and this consonance making ye object seen with two eyes appear but one for ye same reason that unison sounds seem but one sound.[33]

It is possible that Adrien Auzout, in Paris, was the source for some of the speculations about colour harmony: Henry Oldenburg wrote to Robert Boyle in 1668 telling him about Auzout's ideas in general terms, although we have no evidence that this was ever brought to Newton's attention, nor do I have any more detail about Auzout's colour harmony than Oldenburg gave, the gist of which was that Auzout believed advantages would derive for painting if men could learn to recognise ratios expressed in colour as easily as those expressed in pitch. Oldenburg reported that there was disagreement in France about whether this was possible.[34] A week later Oldenburg quoted similar remarks from Nicole Poisson's commentary on Descartes' *Compendium musicae*, about the advantage of the ear over the eye in making comparisons.[35]

Non-Mechanical Causes

Robert Boyle participated in musical experiments at his rooms in Oxford during the plague year 1665, but there seems to be no record of their details.[36] He was also interested in the effects of vibration more generally. For example, he noted that Athanasius Kircher mentioned 'a correspondence between some liquors and some determinate sounds', but that his own attempt to reproduce this did not succeed.[37] The con-

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[32] Kaplan B.B., "Briggs, William", in *Oxford Dictionary of National Biography* (Oxford: 2004): <http://www.oxforddnb.com>.

[33] McGuire J.E. – Tamny M., *Certain Philosophical Questions* 225, and see Isaac Newton, *Correspondence* II 377–8: Newton to Briggs, 20 June 1682.

[34] Robert Boyle, *Correspondence*, M. Hunter – A. Clericuzio – L.M. Principe (eds.), (London: 2001) IV, 44: Oldenburg to Boyle, 10 Mar 1668.

[35] Ibid. IV, 46–7: Oldenburg to Boyle, 17 Mar 1668.

[36] On the experiments see Henry Oldenburg, *Correspondence*, Rupert Hall A.R. – Boas Hall M. (eds.), (Madison and London: 1965–77) II, 530, 537, 555. On Boyle's failure to produce a write-up of them see ibid. III, 61–2, 66 and Birch T., *History* II, 68, 83.

[37] Robert Boyle, *An Essay of the Great Effects of Even Languid and Unheeded Motion* (London: 1685) 83–4, citing Athanasius Kircher, *Musurgia universalis, sive ars magna consoni et dissone* (Rome: 1650) I, 38.

text was a discussion of sympathetic resonance, including the case of glasses responding to particular pitches; but it seems likely that this was a slightly confused reference to the sounding-glass experiment discussed above. Boyle also wrote about an experiment in which water was placed in the rim of a bell and the bell struck, which bore some similarity to Hooke's sounding-glass experiment, although Boyle was not interested in vibration as a model for gravitation, as far as I know.[38]

Many of Boyle's references to vibration are collected in his treatise *An Essay of the Great Effects of Even Languid and Unheeded Motion* (1685), which dealt quite generally with the large-scale effects of small-scale motions, usually vibrations. Boyle did not confine his interest in sympathetic resonance to evidently mechanical effects, in contrast to Hooke, who, whether or not he thought that resonance itself was mechanical, always used it to explain corporeal rather than incorporeal effects. Boyle, however, included among his examples of resonance the effect of the tarantella (a dance tune widely believed to cure spider bites) on the human soul and body and the effect of hearing one's name spoken while asleep.[39] Perhaps these were commonplaces, but they indicate that Boyle was prepared to extend the effectiveness of sympathetic resonance in different ways from Hooke. In an unpublished manuscript Boyle suggested the philosopher's stone could attract angels by 'congruity', which he is likely to have meant in Hooke's vibratory sense.[40]

Diversity and Ambivalence

There is considerable diversity among these examples of the use of harmony in natural philosophy. In the case of Hooke and Boyle, and others who used harmony to provide analogies for efficient causes in their explanations, the question arises of whether these were specifically mechanical causes and whether sympathetic resonance in particular was conceived as mechanical or non-mechanical.

The sympathetic string was a classic example of occult action at a distance in the natural magic tradition: it was also called the magical string, even by Hooke himself. At one place in his *Diary*, we see Hooke

[38] Robert Boyle, *Languid Motion* 121–2.
[39] Ibid. 73, 74–5.
[40] Robert Boyle, *"Dialogue on the converse with angels"*, in Principe L.M., *The Aspiring Adept: Robert Boyle and his alchemical quest* (Princeton: 1998) 310–17 at 311; and see 193.

enjoying the mystificatory aspects of the use of sympathetic resonance. In January 1676, he spoke to a group of friends: 'I told them I could make a string vibrate without giving any sound but told them not how, meaning the sympathetick motion.'[41] A few days later he revealed the explanation to Christopher Wren and William Holder, but under the seal of secrecy:

> Told them my experiment of the vibrations of a magicall string without sound by symphony[,] that touching of it which made the internall parts vibrate – caused the sound[.][42]

And, indeed, some of his other references to music have a similarly magician-like character. For example, 'I told them how I would make all tunes by strokes of a hammer.' And Samuel Pepys records that Hooke 'told me that having course to a certain number of vibracions proper to make any tone, he is able to tell how many strokes a fly makes with her wings [...] by the note that it answers to in their flying'.[43] But none of these magical associations implies that for Hooke musical effects were non-mechanical.

Indeed, the mechanical explicability of the sympathetic string seems to have been quite widely accepted from the 1630s onwards, beginning with Mersenne's explanation for it; Francis North, in 1677, also tackled the question; work which was certainly known to Hooke.[44] Hooke himself attempted a more detailed, though unconvincing, mechanical explanation. Conversely, assertions of the nonmechanical nature of the phenomenon are difficult if not impossible to find in the late seventeenth century. Certainly none of the writers mentioned above tells us that he believes the analogy of sympathetic vibration is a nonmechanical one.

Hooke, for example, may have thought sympathy was a basic type of mechanical effect, not explainable in more fundamental terms; he may have thought it nonmechanical, and therefore inexplicable mechanically; he may have thought it both mechanical and capable of mechanical

[41] Robert Hooke, *Diary* 209.

[42] Ibid. 211.

[43] Samuel Pepys, *Diary*, Latham R.C. – Mathews W. (eds.), (London: 1970–83) VII, 239. Cf Robert Hooke, *Micrographia* 72–3.

[44] Robert Hooke, *De potentia*; North F., *A Philosophical Essay of Musick, directed to a friend* (London: 1677); and see Kassler J.C., *The Beginnings of the Modern Philosophy of Music in England: Francis North's* A Philosophical Essay of Musick *(1677) with comments of Isaac Newton, Roger North*, Philosophical Transactions (Aldershot: 2004).

explanation, probably in terms of contact between particles. The latter is suggested by the fact that in *De potentia* he attempted to give a mechanical explanation of resonance: but at the heart of this explanation was the reassertion that certain bodies had an inherent tendency or disposition to vibrate in sympathy with one another. This suggests a belief in sympathy as a basic type of mechanical effect, but it does not rule out the other possibilities.

Indeed, the ambivalence of resonance as an explanation seems to have been of interest to Hooke: it did not commit him either to mechanism or its opposite. (When Hooke applied the analogy of resonance to human memory, one of the Fellows of the Royal Society objected that this 'seemed to make the soul mechanical'. Hooke was able to deny the charge without backing away from his explanation.)[45] Given that Hooke was an atomist and believed that atoms vibrated, the appeal to resonance was a natural one when other explanations failed, and perhaps too much should not be read into it.

Robert Boyle did seem interested in both mechanical and nonmechanical uses of the notion of sympathetic vibration: he did not seem to think that such an explanation would make the subject mechanical, either in the case of the soul or of the angels attracted by the philosophers' stone.

In Newton's uses of harmony we see a different ambiguity. Recall that his assertion that light and sound embodied the same set of harmonious ratios implied that the two had similar or identical *formal* causes: unlike Hooke and Boyle, for whom harmonious vibration was an explanation by analogy, asserting that two effects had analogous *efficient* causes.

In principle, this gave a precise answer to the question of how best to divide up the spectrum into distinct colours, although as we saw Newton admitted some ambiguity about which musical tuning should be used as the basis for the division. Whatever the musical details, Newton's expectation of finding the same mathematical rules governing different effects was not the same as a modern scientist's expectation of finding common types of mathematical law governing different phenomena: the latter is based on the assumption that those phenomena have similar efficient causes. Newton, rather, assumed that the creation had been put together in such a way that different parts of it embodied the same harmonies.

[45] Birch T., *History* IV 154.

It has sometimes been pointed out that this was close to the 'occult' beliefs of writers like Marsilio Ficino or Robert Fludd, who, broadly, asserted that the same harmonious relationships must govern the structure of the cosmos, the proportions of the human body, architecture, human music, and so on.[46] Some of Fludd's diagrams illustrating that correlation are quite well known.[47]

One manuscript from Newton's later years makes explicit his interest in the occult associations of music. In it he suggests that the story of Pythagoras and the harmonious blacksmith contains the inverse-square law of gravitation, 'encoded', so to speak, in an erroneous statement of the relationship between the tension of a string and its pitch.[48] This document has sometimes been used to place Newton in an occult tradition of writing on cosmic harmony.[49]

It is important to be aware, I think, that the occult is not the only aspect of Newton's interest in music. In some of his early manuscripts, which I have not discussed here, he was concerned to apply novel mathematics to arrive at a precise description of music itself. In the *Opticks* he used harmony as a formal cause to explain the splitting and mixing of light. In the later manuscript, he made music theory a vehicle for the transmission of knowledge from the ancients to himself. Newton thus exemplifies the variety of stances which could be taken towards music by a late-seventeenth-century natural philosopher.

But, in the *Principia mathematica*, he also provided a mathematically precise description of the propagation of sound through air. This represents the beginning of a new tradition in the mathematical study of music, that of 'acoustics': a tradition which is characteristic of the

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[46] Gouk P.M., *Music, Science and Natural Magic* 224–257: "Isaac Newton, Pythagorean *magus*"; Gouk P.M., "The Harmonic Roots of Newtonian Science", in Fauvel J. – Flood R. – Shortland M., – Wilson R. (eds.), *Let Newton Be! A new perspective on his life and works* (Oxford: 1988) 101–25.

[47] For example Robert Fludd, *Utriusque cosmi majoris scilicet et minoris metaphysica, physica atque technica historia* (Oppenheim: 1617–21) I, 90, where a monochord and its divisions are superimposed on a diagram of the cosmos; repreduced in Gouk P.M., *Music, Science and Natural Magic* 146.

[48] McGuire J.E. – Rattansi P.M., "Newton and the 'Pipes of Pan'", *Notes and Records of the Royal Society* 21 (1966) 108–43.

[49] Most notably by Penelope Gouk, whose account of musical science in the seventeenth century focusses on the extent to which natural scientists' uses of musical analogy are invocations of occult effects. They therefore amount to the incorporation of elements from the natural magic tradition into the mechanical philosophy of early modern science. Music mediates between science and magic, permitting this incorporation to take place without difficulties being perceived. See Gouk P.M., *Music, Science and Natural Magic*, passim.

eighteenth century rather than the seventeenth. The rise of acoustics would drastically alter the range of approaches which a natural philosopher could take to the study of music.

Conclusions

I have outlined two distinct uses of music in natural philosophy, which I have labelled with the terms 'formal cause' and 'efficient cause'. Perhaps the most obvious difference between them is that music as a formal cause provides a mathematically precise way of structuring data after they have been found, whereas the use of music as a source of analogies for efficient causes provides something more like a heuristic, of use to those seeking the efficient causes of phenomena which need not be precisely described.

If a chronological pattern can be discerned, it is that the use of music as a formal cause died out at around the time mechanical philosophy took hold in England. This pattern could, of course, be read as part of a the larger set of changes which was then underway, in the way knowledge was structured and the tools which were used to create that structure.

This pattern can also be linked the the internal development of mathematical and scientific studies of music. A major finding of my doctoral work is that, during this period, natural philosophers were increasingly sceptical about the quantitative judgements of the musical hearing, and about the precision of those judgements. This has significance for the shift between these two uses of music in natural philosophy, because a use of harmony like that of Newton in the *Opticks* requires confidence in the mathematical precision which it embodies.

It is therefore rather telling that Newton believed that the equal temperament would divide the spectrum just as well as the unequal scale which he used in the published *Opticks*. This suggests, as do certain other sources from this period, that the differences between different musical intervals and different musical scales were arbitrary and provisional, consequences of the nature of our sensory apparatus rather than essential to musical sound.[50] If that were the case, the use of the

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[50] See Wardhaugh B., 'Mathematical and mechanical studies' 189–210 and idem, "The logarithmic ear: Pietro Mengoli's mathematics of music" (forthcoming) *Annals of Science* 64 (2007) 327–348.

ratios of musical harmony to structure the data of other phenomena would inevitably lose its force.

But as well as novelty these sources also show continuity. Their main feature, indeed, is not that musical analogies ceased to be used in the later seventeenth century, but that their use survived, and a new meaning was found for them.

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THE MODERN WONDER AND ITS ENEMIES: COURTLY INNOVATIONS IN THE SPANISH RENAISSANCE

Daniel Damler

I

'Aren't there any wonders in Spain?' It is to his companions Andrenio and Argus that Critilo adresses this question. Before they can reply, a town appears before the eyes of the three travellers, a town of mythical beauty. 'What town is there, towering so high that it seems to pierce the sky?' Those thus adressed have no doubt: 'It must be Toledo, which holds so much wise judgement in its walls, that it ought to reach the stars, even though its own star has sunken, lately.'[1]

Baltasar Gracián, in whose *Criticón* (1651–1657) this dialogue is found in the context of a conversation about the wonders of the world, chose the town in central Spain with deliberation: Toledo, the 'wise' Toledo, had something to offer, that no other city of the empire could pride itself on having.

Toledo has always been admired. The town, situated high above the waters of the Tajo that winds through a narrow valley, owes its attraction to its breath taking natural setting. Artists like El Greco, the painter of the spectacular 'View of Toledo' (*Vista de Toledo*), succumbed to its fascination. Charles V preferred to reside in Toledo during his stays in Spain. With its 60,000 inhabitants, the town, truly *ciudad imperial* and crowned by an *alcázar* that Alonso de Covarrubias had transformed

Abbreviations (Archives):

AGI	Archivo General de Indias (Seville)
AGS: CSR	Archivo General de Simancas: Casa y Sitios Reales (Simancas/Valladolid)
AHN	Archivo Histórico Nacional (Madrid)
AM (Toledo)	Archivo Municipal (Toledo)
APM	Archivo General del Palacio Real (Madrid)
FA	Fürstliches und Gräfliches Fuggersches Stiftungsarchiv (Dillingen a. d. Donau)

[1] For the Spanish text: Baltasar Gracián, *El criticón*, ed. Santos Alonso, 4th ed. (Madrid: 1990) 315.

into a magnificent renaissance palace, was one of the major cities of the Iberian Peninsula.

From the picturesque location, however, arose a number of problems and troubles. The city is situated almost one hundred metres above the river. Yet, it depended on the water of the Tajo to supply its inhabitants with drinking water and to assure the watering of the newly designed royal gardens. For centuries the water had been brought there by water carriers (*aguadores*), who circled up and down the steep paths from the river to the castle and back.

In 1575 Ambrosio de Morales tells of bitter complaints from among the emperor's entourage about the water shortage in Toledo, 'the town being situated so high and the river Tajo having cut itself so deeply into the valleys it flows through. An Italian called Juanelo Turriano got word of the annoyance spreading at court, and Morales, who was well acquainted with him, reports that from that day his interest in the problem never waned.'[2] Years later Turriano managed to construct a conveyor system that could transport the water of the Tajo up to the city. Thus, the water transportation of Toledo was revolutionised.[3] No other technical project of the Spanish 'Golden Age' stirred as much interest among the contemporaries. In the *Tesoro de la lengua castellana* the mechanism in Toledo exemplifies the mechanical invention as such: 'Those machines, ingeniously invented, we call *ingenios*, like the *ingenio del agua* in Toledo, that reaches from the river Tajo right up to the castle and was an invention of Juanelo, the second Archimedes' runs the entry for *'ingenio'*.[4]

It is this technological project of the renaissance, its development and impact, to which I will devote this essay. Section two (II) traces

[2] "Juanelo Turriano, que oyó esta plática, con muy estimado (según él me contado) en cómo se podría subir el agua a aquella tan inmensa altura, y fabricando con el entendimiento la suma de la idea y modelo de su máquina, lo dejó estar reposando, por andar entonces muy embecedido en la fábrica de su reloj [...]" – Morales A. de, *Las antegüedades de las Ciudades de España, que van nombradas en la Coronica, con la aueriguacion de sus sitios, y no[m]bres antiguos* (Madrid: 1792/1999) [1st ed. Alcalá de Henares: 1575] 331.

[3] The project has, so long, been of interest mainly in the field of technical history. Cf. Beck T., "Juanelo Turriano (1500–1585)", *Beiträge zur Geschichte des Maschinenbaues* 1899 365–390; – Porres Martín-Cleto J., *El artificio de Juanelo* (Toledo: 1987); – García Tapia N., *Ingenieria y Aequitectura en el Renacimiento español* (Valladolid: 1990) 268–292; – García-Diego J.A., "Juanelo Turrianos Wasserhebewerk in Toledo", in Frontinus-Gesellschaft (ed.), *Die Wasserversorgung in der Renaissancezeit* (Mainz: 2000) 270–276.

[4] Sebastian Covarrubias de Orozco, *Tesoro de la lengua castellana o española* (Madrid: 1977) [1st ed. Madrid: 1611], s.v. 'ingenio', fol. 504v. (737).

the outlines of Juanelo Turriano's biography and places his activities in the context of the medieval tradition of 'courtly mechanics'. This context subsisted throughout the 16th century, although with substantial modifications. Under the reign of Philip II it was – contrary to a common interpretation – above all, the crown that attempted to initiate and form technological change. Section three (III) dwells on the contrast between the hostilities to which Turriano was exposed by the urban community, and the enthusiasm expressed by the majority of the artistic and literary elite with regard to his invention.

The final section (IV) deals with the contractual 'architecture' of the project and outlines basic elements of a *general* model of financing for innovation.

II

Turriano (1500–1585) was born in a village near Cremona in Lombardy. The famous doctor and mathematician Giorgio Fandulo is said to have been teacher to the young Giovanni in Padua. Since the 1520s he worked as a clockmaker in Milano. At what period precisely, and on what occasion Turriano first met Charles V cannot be reconstructed with certitude. There are some reasons to presume, that the first meeting took place in the years 1529/30, when the emperor travelled to Bologna. Turriano, it appears, was the only person, who succeeded in creating a duplicate of Giovanni Dondi's famous astronomical clock from the 14th century, which the town of Milano wished to present to Charles as a gift. Whether by this achievement or any other: the emperor appears to have been so much impressed by the Lombardian clockmaker, that finally, in 1554, he summoned him to Brussels. From there, Turriano accompanied the Habsburgian to Yuste, where he stayed until the latter's death.[5]

It is a myth that after his abdication the emperor spent the last two years of his life, 1557 and 1558, as a monk in an austere, drab cell in a monastery.[6] Doubtlessly religious motives were, amongst others, an

[5] About Turriano as the emperor's clockmaker: García-Diego J.A., *The man and his legend* (Madrid 1986) 81 et sqq.

[6] On the historiographical reception and on the actual stay in Yuste: Fuchs M., "Kaiser Karl V. Mythos und Wahrheit", in Martínez Millán J. (ed.), *Carlos V y la quiebra del humanismo político en Europa* (1530–1558) vol. III (Madrid: 2000) 85–104; Kohler A.,

inducement as to the choice of the place. He had retired to a monastery of the Hieronymites once before – in 1539, after the decease of his wife – and he was attached to the order.[7] From one of his chambers in the upper storey he could see the high altar, and he was privileged with direct access to the church of the monastery. His confessor, Juan de la Regla, read to him from the writings of Saint Bernard or Augustinus. Mondays and Fridays he attended the mass in the monastery, on other days the priests came to him. But all this did not mean a monastic, an abstemious life. On the contrary, Charles had excellent meals – due to the fecundity of the region he could enjoy a great variety of most delicious dishes – and he ate more than his doctors thought advisable. He continued writing letters and receiving visitors. Reading, conversation and prayers took place in a renaissance villa arranged especially for him, in the midst of Flemish tapestries, carpets, silver crockery and exquisite furniture and paintings. Charles, son of Philip the Handsome, the short-lived heir of Burgundy, could and would not in his old age – certainly not then – deny his origins. Among his books in Yuste were the works of Olivier de la Marche praising Charles the Bold's splendid deeds.

This demonstratively knightly attitude is not inconsistent with the emperor's interest in clocks and mechanisms. The remaining inventories prove that Charles did occupy his time with clocks and that he kept them in his private caskets. In his will, legacies in favour of the 'clockmakers' Turriano and Balin suggest that his interest in mechanical arts was unbroken to the last.[8] But the bourgeois and industrial age errs in interpreting this interest as indices of a middle-class, non-aristocratic tendency in the disposition of the old, powerless, 'private' emperor.

The innumerable 19th-century engravings and paintings showing Charles in his or in Turriano's workshop seem (apparently not without satisfaction) to contain the message that the emperor, who had passed his days in velvet and silk, had, as his life was drawing to a close, learned to appreciate the value of a simple craftsman's existence. In truth however,

Karl V. 1500–1558. Eine Biographie (Munich: 1999) 356–378. Overviews of the emperor's last years of life: Ignacio Tellechea J., *Así murió el Emperador. La ultima jornada de Carlos V. Yuste, 21 Septiembre 1558* (Salamanca: 1995); García Simón A., *El ocaso del emperador* (Madrid: 1995); Cadenas y Vicent V., *Carlos de Habsburgo en Yuste* (Madrid: 1984).

[7] Cf. Seibt F., *Karl V. Der Kaiser und die Reformation* (Berlin: 1990) 220.

[8] Cf. also Morales A., *Las antigüedades de las ciudades de España* 331: '[...] y venido a España su Magestad, y retirado en el Monasterio de Juste, ninguna cosa humana llevó allí para su recreacion sino a solo Janelo y su relox, a allí tuvo hasta su muerte.'

Charles' inclinations were anything but unusual or incompatible with the requirements of his birth and rank.

The penchant sovereigns and the courtly entourage cherished towards refined mechanisms that told the time or were simply entertaining, had a long tradition in Europe.[9] First impulses had once come from the Orient. Charles the Great is said to have received the valuable gift of a water clock from the Caliph Hārūn ar-Rašîd. Later, the emperor Frederick II was presented with a similar gift by the Sultan al-Ašraf. In the *Libros del saber de Astronomia* attributed to Alfons X of Castilia the different forms of construction also play an important role. To seek the company of a clockmaker was considered worthy of a prince long before the 16th century. In the *Songe du Vieil Pèlerin* Philip de Maizières mentions the clockmaker Dondi, who was in the service of the Count of Vertus. Dondi is said to have received the considerable salary of 2000 Florins per annum. The *L'Horloge amoureuse* gives evidence of how close the art of mechanical time telling was linked to the aristocratic culture of the 14th century. The work, 'an elaborate comparison between the various parts of a clock and the familiar allegory of courtly love',[10] was written by Jean Froissart, the poet of chivalrous society.

The staging and refining of 'courtly mechanics' reached its zenith under the direction of the dukes of Burgundy. Fully conscious of the precarious geopolitical situation of their territories and strongly led by their rivalry with the French court, their desire to distinguish themselves had no limits. Their receptions were spoken of throughout Europe. They created for their own amusement, and for their guests', virtually perfect dream worlds that exceeded all previous entertainment in extravagance. Their guests' diversion was not only secured by a huge menagerie of exotic wild beasts, amongst them leopards, monkeys, dromedaries and Indian hens, but likewise by a park entirely devoted to mechanisms for amusement, the so-called *engiens d'esbattement*.

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[9] On 'artificial marvels' and 'wonders at court': Daston L. – Park K., *Wonders and the order of nature 1150–1750* (New York: 1998) 88–108. On the automata-wonders as a part of courtly self-representation: Heckmann H., *Die andere Schöpfung. Geschichte der frühen Automaten in Wirklichkeit und Dichtung* (Frankfurt am Main: 1982) 120–123; – Franke B., "Automaten in höfischen Lustgärten der Frühen Neuzeit", in Grubmüller (ed.), *Automaten in Kunst und Literatur des Mittelalters und der Frühen Neuzeit* (Wiesbaden: 2003) 247–267.

[10] Sherwood M., "Magic and Mechanics in Medieval Fiction", *Studies in Philology* 44 (1947) 567–592, 583.

The lavish use of water or other liquids always played an important role as a sign of abundance, undoubtedly some distant memory of the oriental origins of this technical show. In Burgundy, for instance, a table fountain was constructed of gilded silver and enamel. From its 32 richly decorated spouts poured wine and scented water that in turn rang little bells. At the pheasants' celebration in Lille in February 1454, a highlight of the culture of courtly festivity, the host presented a miniature castle, from the towers of which gushed orange-perfumed water.[11] Likewise, the machines in the park of Hesdin, formerly commissioned by Robert of Artois and carefully renovated under the orders of Philip the Good in 1432, attracted great attention. The guests could gloat over mechanical monkeys, hydraulic stags and water spouting birds, but also had to put up with the silly tricks of the automata, like jets of water suddenly squirting from books or mirrors.

To be sure, such staging was not without function. It did not merely serve to dissipate an overfed upper class, bored with their own inactivity. The dukes of Burgundy hoped for solid political advantages by displaying to the world their wealth and financial superiority. This, however, did not change the fact that those technical marvels with their fountains of scented water did not satisfy any essential human need.

The taste of the court of Burgundy lived on in the emperor's inclinations – though far less marked than formerly. Turriano was meant to help keep the memories awake. In a description – which is doubtlessly greatly exaggerated – of the technical toys Charles allegedly surrounded himself with, it is said, that after lunch, he set up mechanical soldiers and horses for a battle. While the artificial warriors marched over the table, complete with trumpets and drums, little wooden sparrows flew around the room. The report is dated from the first part of the 17th century.[12] Ambrosio de Morales also mentions Turriano's skill in constructing complicated automata. He attributes to him the design

[11] Cf. Flachenecker H., "Automaten und lebende Bilder in der höfischen Kultur des Spätmittelalters", in Grubmüller K. (ed.), *Automaten in Kunst und Literatur des Mittelalters und der Frühen Neuzeit* (Wiesbaden: 2003) 173–195, especially 182–191.

[12] 'Et vero hic in primis fuit, qui in eo Hieronymiano secessu, novis quotidie machinationibus, Caroli mentem, talium rerum avidam oblectabat. Nam saepe a prandio armatas hominum & equorum icunculas induxit in mensam, alias tympana pulsantes, tubis alias occidentes, ac nonnullas ex eis infetis sese hastulis incursantes. Interdum ligneos Passerculos emisit cubiculo volantes revolantesque: Coenobiarcha qui tum forte aderat praestigias subverente'; Strada F., *De bello Belgico decas prima. Ab excessu Caroli V. Imp. usque ad initia ad Praefecturae Alexandri Farensii Parmae, ac Placentiae Ducis III* (Antwerp: 1649) 13–14.

and creation of a woman, dancing to the rhythm of a drum she beat herself.[13]

After the emperor's death, his son, Philip II, presumably from motives of affection, took the Italian into his services – 'with the commitment that you reside in Our court.' His orders remained unchanged: to help with the construction of clocks ('[...] y nos ayáis de seruir y seruáis en hazer los regoles y otras cossas de vuestra professión que por nos os fuere mandado').[14] In reality however, the heir did not share his father's enthusiasm for clocks and mechanical automata.[15] A new age had begun, an age that had but little appreciation of such lavish, frivolous waste as Burgundy had celebrated. Now, everything had to be directly, or at least indirectly compatible with the new political guiding principle, the 'public welfare'. Turriano's plans for Toledo suited this ideal perfectly. Apparently, the plan was approved immediately by the king and his secretaries. On 25 August 1563, Philip exempted the clockmaker from the obligation of his presence at court for the time of his journey to Aragon. If he wished to visit Toledo for official reasons ('[...] a hazer ciertas cossas de vuestra professión tocantes a mi serucio'), he might do this as often as he chose, without any disadvantages arising him from these circumstances.[16] Barely two years later, on 16 April 1565, Turriano, the town of Toledo, represented by Alonso Dáualos, the *regidores* Gutierre de Gueuara and Francisco de Rojas, and, on behalf of the king, the counsellor Dr. De Lagasca, signed a contract about the construction of a 'mechanism' (*ingenio*), that should be able to supply the *alcázar* and the inhabitants of Toledo with 12,000 litres of water a day.

In this sense, Turriano's life symbolises the smooth transition from mechanics of luxury and dissipation to useful machines, the transition from the *engiens d'esbattement* of an over-refined civilisation to technical devices employed for infrastructural purposes. Under his charge

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[13] 'Tambien ha querido Janelo por regocijo renovar las estatutas antiguas que se movian, y por eso las llamaban los griegos Automatas. Hizo una dama de mas de una tercia en alto, que puesta sobre una mesa danza por toda ella al son de un atambor que ella misma va tocando, y da sus vueltas, tornando adonde partio [...]' – Morales A. de, *Las antigüedades de las ciudades de España* 341.

[14] Philip on 16 July 1562: APM, Cédulas Reales, vol. II, fol. 224r. (quotations from: ed. V.L. Cervera, *Documentos Biográficos de Juanelo Turriano* (Madrid: 1996) [DBT], Doc. 5, 20–21).

[15] Cf. García-Diego J.A., *Juanelo Turriano, Charles V's clockmaker. The man and his legend* 117–118.

[16] Philip on 25 August 1563: APM, Cédulas Reales, vol. II, fol. 378v. (DBT, Doc. 9, 28).

the courtly store of tricks and ingenuity was transformed into a chest of useful treasures. Turriano's predecessors, too, who had before him tried their luck, were, without exception, specialists, who stood in the service of the king or the courtly entourage. Amongst them had been the Frenchman 'Luis de Fox'[17] or the Flemishman 'Maestro Jorge', who worked as *fontanero* in the royal gardens in and around Madrid.[18] At the request of the Marqués de Zenete, Charles' *camarero mayor*, German engineers had once come to Toledo, planning to solve Toledo's water problems by applying the methods used in the mines of their country. The connection between 'useful' and 'decorative' technical devices is even more evident at the beginning of the 17th century, when Salomon de Caus (1576–1626), in his famous book on machines, explains to the reader that 'the [mechanisms] described in this book/serve partly as devices of general use/partly as decoration of the palaces and gardens.'[19]

On a broader scale it can be said that, in Spain, the crown was, in fact, the motor of technical and scientific 'modernisation'. At the beginning of the 80s the *Academía de matematícas* was founded with Philip's explicit support. By recruiting experts in the fields of cosmography, geography, architecture and mathematics, the focus was put on the promotion of the applied sciences. The money order for Juan Bautista Labaña, who was to teach mathematics and study *cosmografía, geografía y topografía*, contains a description of the aims of these measures: 'For the welfare of our vassals and that there may be specialists in my kingdom, who know mathematics as well as the art of architecture and the other sciences connected with it [. . .]'.[20] It was, as can be seen from the same

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[17] '[. . .] que yo le [Luis de Fox] hago merced por una bez por la costta que hizo en hazer por nuestro mandado ciertos modelos e yngenios a propósito subir el agua a la dicha ciudad' Philip on 15 September 1569: APM, Cédulas Reales, vol. II, fol. 407v. (DBT, Doc.; 11, 31).

[18] A hint as to 'Maestro Jorge's' and 'Juan de Cote's' failed attempts can be found in a letter to the secretary Martín de Gaztelú: [. . .] 'prouaron por mandado de Su Magestad a subir la dicha agua aunque no saliera con ello'; – AGS, CSR, leg. 271, fol. 79.

[19] Salomon de Caus, *Von gewaltsamen Bewegungen. Beschreibungen etlicher, so wol nützlicher alß lustigen Machiner beneben unterschiedlicher abriessen etlicher höllen od' Grotten und Lustbrunnen* (Frankfurt am Main: 1615) *Vorrede* (unfol.). The French version was published 1615, likewise in Frankfurt, under the title: *Les Raisons des forces mouvantes avec diverses machines tant utilles que plaisantes, aus quelles sont adjoints plusieurs desseigns de grotes et fontaines.*

[20] APM, Cédulas Reales, vol. VI, fol. 210 (quotations from: Vicente Maroto M.I. – Esteban Piñeiro M., *Aspectos de la ciencia aplicada en la España del siglo de oro* (Salamanca: 1990), *Apéndice documental*, Doc. 7, 115.

document, a foundation 'en mi corte', the creation of an institution directly assigned to the court.

At first (until 1591) two professors were employed for teaching and research: along with the aforementioned Labaña, there was Pedro Ambrosio Ondériz.[21] Later on, the number of courses offered was continually extended, for instance in 1595 by the establishment of an additional *catedra* and the appointment of the mathematician Dr. Ferrofino, who had previously been engaged in Philip's services as his legal representative in Rom 'mi abogado an corte rromana'. With regard to his teaching duties, the text of his appointment runs as follows: 'Herewith I appoint and raise him to the position of professor of mathematics, that he might give two lectures a day at my court, one in the morning and the other one in the afternoon.'[22] A close vicinity to the court was assured by the purchase of a house as quarters for the academy that had formerly belonged to the Convento de Santa Catalina de Sena and was situated only a few steps from the royal *alcázar*.[23]

The Library of the Escorial was, likewise, a first rate centre for information and research, systematically and most carefully kept up to date.[24] The crown committed itself with zeal to the promotion of the printing of works on practical sciences, on cartography, on architecture in general, the construction of fortresses in particular, on munition and weapons, on mechanics, on the production of coal, iron and steel and on the mining industry. The extent to which these activities were pursued has been brought to light only in the last few years. It is largely to be imputed to the protestant, enlightened notion of the 'dark splendour' of the Spanish monarchy, of its backwardness and reluctance towards innovation that this aspect of Philipian politics could fall into oblivion.[25]

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[21] AGI, IG-874 (quotations from: Vicente Maroto M.I.; – Esteban Piñeiro M., *Aspectos de la ciencia aplicada en la España del siglo de oro, Apéndice documental*, Doc. 16, 122–124).

[22] AGI, IG-874 (quotations from: Vicente Maroto M.I.: – Esteban Piñeiro M., *Aspectos de la ciencia aplicada en la España del siglo de oro, Apéndice documental*, Doc. 24, 130).

[23] Vicente Maroto M.I. – Esteban Piñeiro M., *Aspectos de la ciencia aplicada en la España del siglo de oro* 88–89.

[24] Cf. Sanchez Ron J.M., "Felipe II, El Escorial y la ciencia europea del siglo XVI", in *La ciencia en el Monasterio del Escorial* (San Lorenzo de El Escorial: 1994) 41, 44–50.

[25] Cf. especially Vicente Maroto M.I. – Esteban Piñeiro M., *Aspectos de la ciencia aplicada en la España del siglo de oro* (Salamanca: 1991); – García Tapia N., *Ingeniería y arquitectura en el Renacimiento español* (Valladolid: 1990); – Goodman D.C., *Power and penury. Government, technology and science in Philip II's Spain* (Cambridge: 1988); – Goodman D.C.,

In their own perception, the scientists thus promoted were always servants of the king, too, standing in a long tradition of scientific counsellors of sovereigns, which endowed them with the necessary legitimacy. In his *Libro de los reloges solares* (1575), Pedro Roiz recalls the glorious days, when mathematicians are said to have, for the general good, assisted the mighty and powerful with word and deed:

> Those who write about the accomplishments a sovereign has to possess, mention as one of the most important the knowledge of mathematics (of which Julius Caesar, Octavianus, Tiberius Caesar, Antonius and our Catholic King and master Don Alfonso bear witness, as well as the advice Aristoteles gave Alexander when he recommended him to do nothing without having previously consulted a good mathematician).[26]

III

Turriano set to work and realised what he had promised and even more. In record time, the third year was not yet over, on February 23 1569, he managed to finish a functioning construction.[27] In May, the *corrigedor* and representatives of Toledo inspected the machine.[28] They took note of the fact that the amount of water thus transported was more than twice the amount originally agreed upon.[29] Turriano, having fulfilled his part of the mutual obligations, now expected the town to fulfill theirs. He was already preparing for the construction of a second machine, when it became clear that at the town hall nobody dreamt of paying the Italian the sum he had been promised in case of a successful implementation of the project. This was the beginning of a dispute about Toledo's debts that lasted for years and brought Turriano to the brink of despair. He made recourse to their promise, the promise made by the representatives of the council; he recalled his own debts and

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"Philip II's patronage of science and engineering", *The British Journal for the History of Science* 16 (1983) 49–66.

[26] Pedro Roiz, *Libro de los reloges solares* (Valencia: 1575) *Epistola del Auctor.*

[27] Juanelo Turriano to Philip (n.d.): AGS, CSR, leg. 271, fol. 230.

[28] '[…] acabé la dicha obra antes del treze de Mayo del mesmo año de sesenta y nueve, y en el dicho dia pessaron el agua el corregidor y otras personas diputados por el Ayuntamiento […]' – Juanelo Turriano to Philip (n.d.): AGS, CSR, leg. 271, fol. 233.

[29] 'que viene ser la mitad por medio mas del agua que prometio'; – Juanelo Turriano to Philip (n.d.): AGS, CSR, leg. 271, fol. 233.

warned that as he lacked the money to finish some necessary work, the machine was in danger of sustaining damage.[30]

As there was no reaction on the town's side, Turriano begged for the king's intervention to help him obtain what was clearly his right. The king accordingly intervened, demanded *ayunamento y corregidor* to fulfil their promise and ordered the appointment of persons that should bring the affair to a quick end.[31] In vain. Surely, the king having spoken so clearly, the town could no longer simply ignore the petitions Turriano sent to the town hall. The municipal bodies sat regularly to discuss the matter. But all claims were rejected on the grounds of it being out of the question to fulfil the contract, as Turriano himself had not discharged his duties, and as, moreover, the city had, as yet, 'not profited by the water conveyor system, nor ever will.' Most of the water was not of any benefit to the town's folk, but only to the royal *alcázar*.[32]

Not only was his fair salary withheld, Turriano had to struggle, day after day, with the municipal authorities, who refused him the necessary materials or created obstacles of every kind. It was doubtlessly not quite by accident that large quantities of excrements and rubbish were dumped on the building site. Aside from all other disagreeable effects, this damaged the building wood. The engineer's complaints called the king and his secretaries into action. 'Ensure and arrange', it read in an order to the *corrigedor* of Toledo dated from 1570, 'that in the vicinity and the surroundings of the building site nobody may put up his manure heap nor spread his rubbish.'[33]

The miserable economic situation Turriano was facing as a consequence of the city's refusal to pay was ultimately threatening the entire project. When it became obvious, that a lengthy lawsuit was to be

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[30] 'porque ay necesidad de cubris algunas partes del dicho hedificio y de hazer algunos perdones para la perpetuidad dél, y de la dilacion desto podria el dicho hedificio recibir daño'; – Juanelo Turriano to Philip (n.d.): AGS, CSR, leg. 271, fol. 231.

[31] Philip to the *ayuntamiento y corregidor* of Toledo on 12 December 1573: APM, Cédulas Reales, vol. IV, fol. 59r. (DBT, Doc. 31, 77).

[32] "Pues la mayor parte dellos están consumidos y azensuados en la ocasiones que se an ofrecido tan precisas y del servicio de vuestra magestad"; – Toledo to Philip on 29 October 1574: AM (Toledo), Libro de Actas 12 (DBT, Dok.Nr. 40, 89). The letter had been proceeded by a conference of the *ayuntamiento* on 24 October 1574: AM (Toledo), Libro de Actas 12 (DBT, Doc. 39, 88). Similar reasons are given in the letters to the king of 11 November 1574 (AGS, CSR, leg. 271, fol. 232) and 18 January (AGS, CSR, leg. 271, fol. 236), also in the minutes of the meeting on 15 January 1575: AM (Toledo), *Libro de Actas* 12 (DBT, Doc. 39, 98–99).

[33] Philip to Diego de Cuñiga on 1 October 1570: AHN, Consejos, Libro de Cámara 252, fol. 23 (DBT, Doc. 20, 49).

expected, the expenses of which Turriano could hardly have afforded, the secretary responsible, Martín Gaztelú, after prior consultation with the king, intervened in the dispute. In an informal, confidential letter to the *corrigedor* of Toledo and *regidor* Gaetán de Ayala, he appealed to the common sense and reason of the parties. In the first place, the secretary sought to sound out the possibilities of an extra-judicial settlement and to prevent further escalation. 'Your majesty has declared', wrote Gaztelú in September 1574, 'that, as this matter is of such a quality and as Joanelo has invested so much money and is charged with so high an interest rate', a rapid solution must be found, 'likewise taking into consideration his advanced age and the fact that he acted in good faith and by orders of her majesty.' The dispute was either to be settled by consensus, which is to say by means of a new contract ('por concierto'), or by legal action, which meant appointing judges who were to decide in an accelerated procedure ('breuue y sumariamente').[34]

The municipal representatives reacted with reserve, but they did react. The affair was discussed in different meetings in autumn 1574.[35] Being convinced that 'voluntad y yntencion de su magestad' could not be disregarded, Toledo consented to solve the problems by negotiation. This, however, was not meant as an acknowledgement of a past misconduct on the part of the municipal representatives, and even less as a confirmation of Turriano's claims.[36] Toledo's interests were to be represented by the *regidor* Gaetán de Ayala,[37] who was formally authorized on 29 October 1574 'to conclude for us, in the name of this town, whatever contract or agreement you choose and consider proper, with the afore mentioned Juanelo Turriano.' Ayala was, however, to take into consideration the legal interpretation of the affair in the municipality, according to which 'an enormous damage' for the

[34] AGS, CSR, leg. 271, fol. 176.

[35] Meetings of the *ayuntamiento* on 27 September 1574: AM (Toledo), Libro de Actas 12 (DBT, Doc. 35, 84); – on 1 Oktober 1574: AM (Toledo), Libro de Actas 12 (DBT, Doc. 36, 85); – on 6 October 1574: AM (Toledo), Libro de Actas 12 (DBT, Doc. 37, 86); – on 24 October 1574: AM (Toledo), Libro de Actas 12 (DBT, Doc. 38/39, 87–88); – on 10 January 1575: AM (Toledo), Libro de Actas 12 (DBT, Doc. 45, 97); – on 15 January 1575: AM (Toledo), Libro de Actas 12 (DBT, Doc. 46, 98).

[36] 'tinyendo más consideración a la voluntad de su magestad que a la justifucación de la pretensión de Juanelo; – Meetings of the *ayuntamiento* on 6 October 1574: AM (Toledo), Libro de Actas 12 (DBT, Doc. 37, 86).

[37] Toledo to Philip on 29 October 1574: AM (Toledo), Libro de Actas 12 (DBT, Doc. 40, 89).

city derived from the contract ('ciudad hauía sido inormísssimamente lessa e damnificada en el dicho asiento') and that consequently Toledo could demand amends.[38] Turriano, too ill and weak to take part in the negotiations ('enfermo en la cama y con legítimo impedimento') sent his grandson, Juan Antonio Fassole, in his place.[39]

On the king's side, the Conde de Chinon and Don Yñigo de Carenas took over the task of working out a compromise that was to be presented to the two disputing parties. The draft of this paper was edited by Philip himself, who, on the whole, approved it. Additions were to be made with regard to the second *ingenio*, however. It was to be mentioned in the text that he, the king, should have the right to use the water from this machine, too, ('[...] si yo en algun tiempo la ubiesse menester la pueda tomare por el tanto'), if necessary. The notes written in the king's own hand show how discontented he was with the conduct of the municipality of Toledo. He comments approvingly on the fine ('Bien hecho') and recalls the economic difficulties of the 'very poor' Turriano. The draft appeared acceptable to all parties concerned, or it may be they had no other choice – whatever the case, the subsequent negotiations brought no substantial change.

According to the contract of 20 March 1575,[40] the purpose of the agreement was to avoid legal processes and their consequences ('para atajarlos pleytos y competencias que dello podrían nacer'). The privileges Turriano was granted were understood by the parties as compensation for the readiness to regard the first contract as dissolved ('se ha tratado y asentado de Nuevo que el dicho Joanelo se desiste y aparta y da por ninguno el dicho assiento y contrato que hizo con la dicha ciudad'). Juan Antonio Fassolo, Turriano's grandson, succeeded in having the sum that was to be paid by the town augmented to 6000 ducats and having all rights and duties transferred to Turriano's heirs. The king ratified the following day, so as not to give the city any opportunity of finding a new pretext.[41] His warning could not be clearer:

[38] APM, Cédulas Reales, vol. IV, fol. 168 (DBT, Doc. 50, 107).
[39] Formal authority from 10 December 1574: APM, Cédulas Reales, vol. IV, fol. 168 (DBT, Doc. 50, 105–107).
[40] *Asiento*, 20 March 1575: APM, Cédulas Reales, vol. IV, fol. 168 (DBT, Doc. 50, 108–112).
[41] APM, Cédulas Reales, vol. IV, fol. 172 (DBT, Doc. 51, 113).

> We wish and it is our will, that everything may be respected and conducted in this way – undisturbed by whatever privileges the town in question is in possession of and unaffected by laws or any other rights and customs withstanding this, and of which, for this case only, we grant a dispensation.[42]

The city of Toledo was not really contented with the contractual 'compromise' the crown had forced upon it. But there was not much sense in continuing the policy of resistance, considering the attention the case had caused at the highest authority – at court. The municipal council formally recognised the obligations towards Turriano[43] and then fixed the mode of payment: 2000 ducats were to be paid immediately, the rest a year later.[44] The financial stringency obliged Toledo to seek the king's permission for a special mode of financing, which the latter gave in November 1575.[45] No one will wonder that Turriano watched every step of the *ayuntamiento* with the greatest distrust[46] and never ceased to attribute to Toledo the entire responsibility for his ruin.[47]

His indignation was, amongst other reasons, not to be appeased, because the city continued to make trouble. Even the royal administrators of the *alcázar* complained of the unwillingness to cooperate displayed especially by the *corregidor*, and of the constant invention of new, spiteful harassments. The list of complaints was long: There were periods where the work on the building site totally collapsed as a consequence of the *corregidor's* refusal to provide necessary materials like lime, wood or stones. The workers had to endure an incessant flow of insults, whereas the construction itself was the object of the most insolent defamation.[48] Worst of all, the *corrigedor* kept the sentinel, the *alguacil*, from doing his duties, and had even consigned him to another post, so that at night, when everybody was asleep, the building site was

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[42] Philip on 25 March 1575: APM, Cédulas Reales, vol. IV, fol. 173 (DBT, Doc. 52, 115).

[43] Meetings of the *ayuntamiento* on 11 April 1575: AM (Toledo), Libro de Actas 13 (DBT, Doc. 57, 124–125); – and on 13 April 1575: AM (Toledo), Libro de Actas 13 (DBT, Doc. 58, 126–127).

[44] Meeting of the *ayuntamiento* on 18 April 1575: AM (Toledo), Libro de Actas 13 (DBT, Dok.Nr. 60, 129).

[45] APM, Cédulas Reales, vol. IV, fol. 280 (DBT, Doc. 69, 140 f.).

[46] AM (Toledo), Libro de Actas 13 (DBT, Dok.Nr. 61, 130).

[47] A year before his death Turriano wrote: 'y que por no aver cumplido Toledo lo que conmigo assentó, estoy pobre que no puedo pagar las deudas que tengo'; AGS, CSR, leg. 271, fol. 242.

[48] Lorenzo Oliverio and Juan Arte de Mazuelo to Martín de Gaztelú on 8. July 1575: AGS, CSR, leg. 271, fol. 183.

unprotected.[49] In this case, Turriano's machine was in great danger, as the numerous tramps ('vagamundos') in the surrounding country were only waiting for an opportunity to seize the machines, to set fire or to dump their rubbish on the grounds. 'It is a miracle', the crown's administration wrote to the secretary Gaztelú, 'that we have not, as yet, witnessed the entire construction being devoured by flames.' The amount of dirt, too, was indescribable.[50]

Madrid, now, finally lost patience. Philip had no desire to witness the technical achievement he had promoted being buried under excrements and rubbish or reduced to smoke and ashes, merely because a few troublemakers had taken to such a scheme. The *corregidor* of Toledo, it thundered from the royal cabinet, was to protect the construction resolutely, so that 'no conflagration or any other catastrophe could be occasioned, and should also, with the utmost determination, find out, shut away and punish those who break the law ('después de presos, castigareys con particular cuydado según el delicto y excesso de cada uno').[51] Whoever attempted to impede the procurement of materials – 'assí de cal, ladrillo, piedra, y yesso, como de madra' – was to be punished.[52] The unauthorised consignement of the *alguacil* to another post, too, was severely censured: In future, Turriano's need of security was to be taken seriously and orders were to be obeyed – 'without inventing pretexts or making difficulties.'[53]

But whatever the king's orders: there was always some way or other to bring Turriano in distress. At best, the malicious actions were more subtly conceived. For instance, the rumour was soon afterwards spread in town, that the water the machine transported had a bad taste. 'What is said about the water taking on a bad taste from the metal pipe lines',

[49] 'Muchas veces auemos escrito a vuestra merced lo que importa tener esta casa un alguacil que siruiese de sobrestante y tomar materiales y otras cosas necesarias por estas obras especialmente para guardar el Yngenio que ya es de Vuestra Magestad que por estar entablado tiene mucho peligro asi de los vagamundos y mal yntincionados'; – *Officiales de las obras del alcázar de Toledo* to Martín de Gaztelú on 15. February 1576: AGS, CSR, leg. 271, fol. 190.

[50] Lorenzo Oliverio and Juan Arte de Mazuelo to Martín de Gaztelú on 8 July 1575: AGS, CSR, leg. 271, fol. 183.

[51] Philip to Joan Gutiérrez Tello on 23 February 1576: APM, Cédulas Reales, vol. IV, fol. 301v. (DBT, Doc. 72, 145).

[52] Philip on 25 August 1575: APM, Cédulas Reales, vol. IV, fol. 239 (DBT, Doc. 66, 136).

[53] Philip on 19 November 1575: APM, Cédulas Reales, vol. IV, fol. 282 (DBT, Doc. 70, 142).

Turriano wrote in April 1585, only a few weeks before his death, 'has been invented by an envious person with bad intentions ('inuencion de algun embidioso no bien intencionado'), to whom one should pay no attention. Therefore, I will not venture to do anything against it, which I certainly would have done, had it been necessary.'[54] That such insinuations were without foundation was confirmed by the 'officials' of the *alcazár*: 'As far as the bad taste is concerned, which is imputed to the water being transported in metal pipes, we have investigated into the matter and have verified the charge, but we have not perceived any derogation.'[55] Turriano took interest in the fate of his invention to the last, although he had, at that period, already offered to give the machine as a gift to the king, as 'I don't think it justified, that a thing of such greatness should be in the possession of any other person than your Majesty.'[56]

How can the sabotage, the silent rebellion against 'a thing of such greatness' be explained? Was there not every reason to rejoice in the successful project – admittedly a masterpiece of engineering – in one's own town?

The reason the municipal authorities of Toledo gave for their refusal to share in the costs of the project, was, as seen, that the city had no portion of the water conveyed, but that the profit was all the king's. Whether the reproach was justified is difficult to ascertain. In Turriano's eyes, the argument was an insidious plea, conceived by the town so as to decline all responsibility.[57]

The official comments contain no hint as to the brains behind the many malicious little stings that made the daily life on the building site unbearable. It might be conjectured, though. One particular group within urban society could have no interest at all in the success of the project:[58] The water carriers of Toledo, the *aguadores* (*acacánes*). The profitability of their business must have once been proverbial. In

[54] Juanello Turriano to Juan de Ybarra on 17 April 1585: AGS, CSR, leg. 271, fol. 243.

[55] Lorenzo Oliverio and Juan Arte de Mazuelo to Juan de Ybarra on 22 April 1585: AGS, CSR, leg. 271, fol. 208.

[56] Juanello Turriano to Philip on 12 November 1584: AGS, CSR, leg. 271, fol. 242.

[57] 'con essa uia que parece de comedimiento querria salir de su obligacion'; Juanelo Turriano to Philip am 15 February 1575: AGS, CSR, leg. 271, fol. 238.

[58] On similar cases of resistance against the use of machines: Popplow M., *Neu, nützlich und erfindungsreich. Die Idealisierung von Technik in der Frühen Neuzeit* (Münster: 1998) 60–64.

Covarrubias' *Tesoro de la lengua castellana* (1611) we read: 'acacán – an Arabic word, employed in the city of Toledo, where the water carriers are usually donkey drivers. They get very rich with only one or two mules. As the town is situated very high up and has no springs, it is necessary to carry up the water from the river.'[59] To these rough and quarrelsome men, the rival, who was menacing their prosperity and their 'wealth', is bound to have been a thorn in their flesh.[60]

But, there was perhaps another, more fundamental reason why the urban community rejected the technical innovation. There is, indeed, a striking disparity between the resistance against the *ingenio* displayed by the town's folk and the enthusiasm of the literary world. Cervantes, Tirso de Molina, Lope de Vega, Quevedo, Gracián and Góngora: they have all immortalized the mechanical water conveyor system in their poetry.[61] The transport from the depths of the riverbed, kept in motion as if by magic, up to the lonely summits of the *alcázar*, 'crown' and head of the town, inspired the poets' imagination. Some saw the crystal-clear tears of the Tajo travelling to the clouds, others a clockwork conducting water right into the sky. They worshipped the creator of the *ingenio* as 'second Archimedes' (Covarrubias Orozco) or as 'Dédalo Cremonés' (Góngora).[62] With breathtaking rapidity the *ingenio* was culturally integrated and was even given a place of honour amongst the most admirable buildings in Toledo and even throughout Spain. Cervantes leaves no doubt about the value of the construction as an object of interest ('lo que dicen que hay famoso'), as he makes clear in *La ilustre fregona*:

> 'Tomorrow we will have to rise rather early, so as to arrive in Orgaz before the heat is worst.'
>
> 'On no account', retorted Avedaño, 'because before I leave the town, I wish to see everything else that is said to be worth a visit: the Sagrario, the *artificio* of Juanelo, the Vistillas de San Augustín, the Huerta del Rey and the Vega.'[63]

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[59] Sebastian Covarrubias de Orozco, *Tesoro de la Lengua Castellana*, s.v. 'acacán', fol. 9v. (35).

[60] How rough things could be among the water carriers is described in Cervantes' *La ilustre fregona.*

[61] Sánchez Mayendía has compiled quotations from literature in: Sánchez Mayendía J.C., "El artificio de Juanelo en la literatura española", *Cuadernos Hispanico-Americanos* 13 (1958), 73–93 (incomplete).

[62] Góngora L. de, "Las firmezas de Isabela", in Millé y Gimenez J. – Millé y Gimenez I. (eds.), *Obras completas*, 3rd ed. (Madrid: 1951) 776.

[63] For the Spanish text: Cervantes M. de, "La ilustre fregona", in Gonzalez Palencia A. (ed.), *Rinconete y Cortadillo y La ilustre fregona*, 3rd ed. (Zaragoza: 1947) 81–82.

Federico Zuccaro, at the time one of the most sought-after painters in Europe, who worked on Philip's orders in the Escorial, praises his compatriot's creation, 'bellisimo ingegno del Gianello eccellentissimo ingeniero nostro italiano', and places it among the three 'cose notabile' of the town at the Tajo.[64] Lope de Vegas finds even more flattering words in *El arenal de Sevilla*. Therein, Turriano's machine appears as the landmark of Toledo, which could stand any comparison with the ancient sights of other Spanish cities.

> Préciese de su edificio
> Zaragoza eternamente,
> Segovia de su gran puente,
> Toledo de su artificio,
> Barcelona del tesoro,
> Valencia de su hermosura,
> La Corte de su ventura,
> Y de sus almenas Toro.[65]

And in the poem *El amanta agradecido* he says:

> Veré a Valencia que es bella
> Y deste allí iré a Madrid
> Pasaré a Valladolid,
> Que ya está la corte en ella.
> En Salamanca veremos
> Amigos con quien oí
> la gramática, y de allí
> a Toledo volveremos.
> Veré la iglesia mayor,
> de Juanelo el artificio[66]

Apparently, in a pleasure trip, a *grand tour* of the cultivated and refined through Spain, a trip to Turriano's invention was paramount. It competed with the courtly show in Valladolid and the exotic gardens of Valencia to win the favour of the spectators. Although the machine was evidently useful, poets and artists described it as an *engien d'esbattement*, as one of those delightful automata from the park of wonders of

[64] Letter of 21 May 1586: Biblioteca Apostolica Vaticana, Urb. Lat. 816 (copy), in Dominguez Bodona, "Federico Zúccaro en España", *Archivo de Arte y Araqueologia* 7 (1927) 77, (annex) 81, 87–88.

[65] Felix Lope de Vega Carpio, *Comedias escogidas* vol. III [BAE 41] (Madrid: 1857) 530.

[66] Felix Lope de Vega Carpio, "El amante agradecido", in Gómez y Paloma Cuenca J. (ed.), *Obras Completas – Comedias* vol. VIII (Madrid: 1994) 6.

Hesdin. This is, however, not so very surprising, when one recalls the text *L'Horloge amoureuse* and other literary models. Highly developed mechanics were, after all, a matter of high cultivation and refined taste.

It may be presumed, that those responsible in Toledo held a similar point of view. From this perspective it is understandable that the city could have no interest in financing the 'bellisimo ingenio'. They felt no responsibility at all for the amusement of the cultural avant-garde. If the king desired to have expensive trick fountains constructed, they argued, he might as well bear the expenditure himself.

Referring himself to Turriano's construction, Gracián does indeed point out the basic connection between artificial marvels and uselessness. The conversation from the *Criticón* about the wonders of the world, cited in the introduction, continues thus:

> 'And what unusual construction is this, making the crystal floods of the Tajo stream right up to his castle?'
>
> 'It is Juanelo's famous *artificio*, one of the modern wonders (*una de las maravillas modernas*).'
>
> 'I don't see why', said Andrenio, 'as the running of so elaborately conceived a construction costs more than it brings. (*si al uso de las cosas muy artificiosas tuvo más de gasto que de provecho*).'
>
> 'The Cardinal Trivulcio thought quite differently about the matter', retorts Argus. 'This exceedingly wise man protested, that there had never been a more useful artifice in the world (*que no había en el mundo artificio de más utilidad*).'[67]

This dialogue is revealing, because there is a hint as to the existence of differences in the perception and evaluation of Turriano's invention. The Cardinal Giangiacomo Trivulcio (1597–1656), formerly viceroy of Aragon and governor of Milano, represents the crown and its unrestrictedly positive judgement of the artificial, 'modern' wonders. From this point of view, the refinement of the construction is not inconsistent with its utility. For Andrenio, on the other hand, the contradiction is evident. Gracián, in the *Discreto* (1646) goes even farther. The *artificio* of Toledo is therein mentioned in the chapter entitled *Contra la Hazañeria*, 'Against boasting'. In order to characterise the kind of man who takes great pains but no sense to put on a show, a person making 'much ado about nothing' ('de pocas cosas mucho ruido'), he refers to Turriano's creation, which he thinks, likewise, loud and useless: 'Thus,

[67] For the Spanish text: Gracián B., *El criticón*, ed. A. Santos, 4th ed. (Madrid: 1990) 315–316.

they exert themselves even more than Juanelo's 'artificio', with the same row and as little gain.'[68]

The divergence of expenditure and gain or, indeed, the complete lack of any aim or purpose in an action, was a stereotypical feature of popular culture – represented by the 'picaros', the rogues and fools – attributed to courtly society. Above all, the courtly ceremony 'al uso de Borgogna', another deluxe import from the north, supplied the mockers with plenty of subjects. Juan Luis Vives let them have their say:

> Holocolas: [...] But let us set foot into the hall where the king dines.
> Agrio: Oh, how many people, how cumbersome and slow the preparations!
> Sofronio: Your surprise will be the greater when you perceive how little gain is derived from it all: merely to have the king eat one egg and, unwillingly, take a sip of wine.[69]

The barrier that blocked the communication between court and town was not as harmless and amusing as it may seem to the unbiased reader of contemporary literature. The Spanish history of the 16th century knows a type of this 'clash of civilisations' accompanied by violent political turbulences. The extravagant and arrogant manner of Charles' Flemish entourage on the occasion of the emperor's taking charge of the governmental affairs, had, indeed, played a prominent role in the difficult take-off of the Habsburgian rule in Castilia. After the rebellion of the *Comunidades* had been put down – a rebellion that had brought the country to the brink of a civil war – enduring peace was restored; but the events were not forgotten so quickly, and the court never quite succeeded in getting rid of the disadvantageous image of promoting the ruin of the country.

The analogy between Vives' depiction of the ceremony at table and Gracián's classification of the *ingenio* of Toledo suggests that the difficulties the technical wonderwork encountered arose simply from the fact that it had been created in the sphere of the court. It fell victim to the association of the courtly world with a bizarre lack of purpose.

The fact that Toledo had, at a very early period, protested first against the construction and then against its enlargement, suggests, that in truth the authorities not merely refused to pay as a consequence

[68] Baltasar Gracián, "El discreto", in Batllori y Ceferino Peralta M. (ed.), *Obras completas*, vol. I [BAE 229] (Madrid: 1969) 355.
[69] Juan Luis Vives, *Diálogos y otros escritos* (Barcelona: 1988) [1st ed. Cologne 1538] 104.

of the usurpation of the amount of water they claimed, and not with regard to an *actual, proven* unprofitability either. From the very first and in every respect it had been the king who had urged the project; the town had followed reluctantly, hoping to get the affair through without being burdened with any obligations. Indifferently, without showing any interest in taking an active part in the project, they had watched the exertions of the year 1561. This conduct did not alter in 1565, nor in 1575. It was not *their* project, it was one that had been forced upon the town, 'que su Majestad mando hazer'.[70] The municipal representatives tried to restrain the sovereign's eagerness, tried to make him understand that Toledo was in no need of a second *ingenio* in addition to the one planned, that, in fact, there was no need even of the first if the town had to pay for it. That Turriano's invention was 'to the benefice and use of this town' ('al bien y beneficio dessa ciudad') was an understanding that had more or less to be forced upon the representatives of Toledo by orders. 'In an affair of such importance and which may be presumed to be a great success ('tam buen subcezzo'), there must be no further delay', was the warning Toledo received even six days before the contract was signed.[71]

One can hardly wonder that those forced to accept such a lot found all sorts of excuses and objections when Turriano presented them the bill for the 'benefice'. The town had no money for an investment to such an amount, and what they did have, they planned to use for other ends, the reparation of the walls, for instance, or other repair work.[72] Toledo was virtually suffocating with representative buildings that had to be maintained. There was no need of yet another attraction, not least, because, as Gracián put it, the city's star was sinking. Since the neighbouring town of Madrid had been made the capital in 1561, Toledo was on the decline, the revenue from trade and industry broke away.[73]

[70] *El Ayuntamiento de Toledo* on 13 October 1561: AGS, CSR, leg. 271, fol. 226. Cf. also Turriano's letter to the town of Toledo (n.d.): 'por mandado de Su Magestad me encargué de hazer subir el agua a los alcácares de esta ciudad'; AGS, CSR, leg. 271, fol. 231.

[71] Cf. also Turriano's letter to the town of Toledo: AGS, CSR, leg. 271, fol. 231.

[72] 'considerando estas causas y la necesidad de los propios desta ciudad que para el rreparo de sus muros, pleytos y otras cosas precisas'; – Toledo to Philip on 18 January 1575: AGS, CSR, leg. 271, fol. 236. Cf. likewise the minutes of the meeting of the *ayuntamiento*: AM (Toledo), Libro de Actas 12 (DBT, Doc. 46, 98 f.).

[73] Cf. Ringrose D., "The Impact of a New Capital City: Madrid, Toledo, and New Castile, 1560–1660", *Journal of Economic History* 33 (1973) 761–791.

There could not have been a more manifest ending of the project than the heirs' of the 'second Archimedes' asking leave to demand admission fees from the numerous visitors.[74] After only a couple of years, the ambitious project had taken on the character of a museum and was very far from fulfilling its actual purpose, and even further from serving as a model for similar initiatives. Thus, a surprising individual transfer of knowledge, the utilisation of the knowledge of mechanical principles to solve problems of infrastructure by a clockmaker, had no consequences, because the transfer of application between the different social and cultural backgrounds failed. It should not be presumed, however, that these parties were not submitted to internal fluctuations, nor that, in general in the Early modern period socially founded differences in the evaluation of technical change blocked such change in the long run, or should even have made it wholly impossible. To date, there has been no proof of that.[75]

IV

Turriano's case, nevertheless, represents what risks there lay in the promotion of innovative projects. Usually, to be sure, the implementation failed even before the question of social acceptance would arise, because the technique of the mechanism would not work. As nobody could avoid noticing the crown's exertions to obtain a favourable starting position in the stiffening competition between the European powers, the court was a great attraction to scores of applicants promising that by some expedition or other in faraway, excessively rich countries, or by some infallible secret weapon or other, the king would eventually ensure his own hegemony. Adventurers, charlatans and visionaries stood in line to obtain benefits and subsidies. This deplorable state of affairs was, among others things, called to notice by Salomon de Caus. In the preface of his work dedicated to Louis XI of France, he recommended the ruler be attentive in the supervision of the scientists,

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[74] *Memorial de los herederos de Joanello* (1586): AGS, CSR, leg. 271, fol. 248.

[75] Cf. Popplow M., "Neu, nützlich und erfindungsreich. Die Ingenieure der Renaissance als Schrittmacher der modernen Deutung von Technik", in Engel G. – Karafyllis N.C. (eds.), *Technik in der Frühen Neuzeit – Schrittmacher der europäischen Moderne, Zeitsprünge* 8 (2004) 336, 350–353.

> damit er nicht von etlichen Fuchsschwäntzern/welche wenn sie vermercken/daß ihr Herr derselbigen [Wissenschaft] nicht verständig/in vorfallenden Sachen ihme ein Werck viel anders vorbilden/als er kann mit Bestandt zuwegen gebracht werden/also/daß es offtmals mit Spott und Schaden muß underlassen werden/hinter das Liecht geführet und betrogen werde [...] Auff solche weise werden Fürsten und Herrn offtmals von ihren Ingeniern und Baumeistern/(so mehr mit nichtigen imaginationibus, als mit gewissen fundamentis versehen) mit unnützigen Wercken angeführet.[76]

The king's delegates in the major cities in Italy, in particular, received inquiries and offers – partly of obviously doubtable, partly of promising contents. It was therefore becoming more and more urgent to separate the wheat from the chaff. To promote everything would have unavoidably meant ruin. In some cases the crown established commissions that were to prove the chances of realisation of a project.[77] But that was not always possible, and, indeed, not without expenses. But there were other means and ways of tackling the problem.[78] Probably most efficient instrument was employed by the crown on the occasion of the plans for the *ingenio* of Toledo, as a second, closer inspection of the agreement from 16 April 1565 reveals.

The principle was quite simple: The crown demanded that its contractual partners realise the project at their own expenses first. Turriano was not even granted an advance to construct his mechanism. He alone bore the risk of failure. Any claims to an indemnification for useless expenses were excluded from the first.

> Should the case occur that the water is not conveyed in accordance to the agreement, the disadvantage and loss of everything that has been invested falls upon master Juanelo, without any liability existing on the side of her majesty or the town above mentioned to pay indemnifications or compensations, neither partly nor for the whole.

It was only after the representatives of Toledo and the king had come to the conviction ('aprobado/visto que el dicho ynstrumento es cierto') that the amount of water agreed upon – 12,000 litres a day – *was*

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[76] Salomon de Caus, *Von gewaltsamen Bewegungen. Beschreibungen etlicher, so wol nützlicher alß lustigen Machiner beneben unterschiedlicher abriessen etlicher höllen od' Grotten und Lustbrunnen*, *Vorrede* (unfol.).

[77] Cf. Goodman D.C., *Power an Penury. Government, technology and science in Philip II's Spain* 129–141.

[78] The following remarks refer to: Damler D., *Imperium Contrahens. Eine Vertragsgeschichte des spanischen Weltreichs in der Renaissance* (Stuttgart: 2008).

indeed conveyed, that the king *and* the town were to pay 8000 ducates each, fifteen days after the day the water had begun to flow. On that day, too, the annual rent was due, to which, according to the contract, Turriano and his heirs were entitled to ever after – 'myll e novecientos ducados de rrenta en cada un año perpetuamente para siempre jamás'. The payment of the rent was effected by the town. It was the king's responsibility to enforce expropriations and to deal with possible damages:

> Item, as there may arise the necessity of seizing some properties by the river, where the instrument or mechanism (*el ynstrumento o yngenio*) is to be constructed, as well as other places or sites situated on the way up to the castle and as it is possible that at some places different persons may be injured in their goods, [...] it must be fixed [...], that neither the above-mentioned master Joanelo nor the town in question will be burdened with any obligations, but that in these cases the responsibility will fall to his Majesty.

The beginning of the promotion did not release Turriano from his responsibility. The contract visibly attempts to establish a long-term and sustainable conception for the use of the machine. It had to be guaranteed that, even after the machine had been completed, Turriano's interest in its functioning did not wane. For instance, according to the agreement, Turriano was to bear the expenses for the reparation and maintenance of the system. He was granted no further financial support in return. The interruption of the water supply had no consequences if it lasted no longer than six days and was occasioned by 'accidental' events ('casso fortuito') like a fire or the flood of the Tajo. Should there be a longer interruption or should the breakdown originate in 'a flaw or defect in the machine in question', Turriano's claims to the rent were put on hold. Likewise, Turriano had to accept discounts, should the amount of water conveyed be smaller than had been agreed, unless the loss was insignificant and not of a permanent nature ('[...] no siendo perpetua y en poca cantidad la que faltare que por quinze días ni un mes no se le desquente cosa alguna'). The Italian also had to promise to bring the canalisation system in order, if necessary.[79] The king claimed the seventh part of the water for the *alcázar*. The town could dispose of the rest.

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[79] On 18 April 1565 the notarial attestation of the contract was effected (*capitulacion, assiento y concierto*): AGS, CSR, leg. 271, fol. 231.

The crown achieved its greatest success with this model of financing not in the field of the promotion of technology, but in another domain. When Gracián and others in the 17th century spoke of the 'huevo de Colón o de Juanelo', ('the egg of Columbus or of Juanelo [Turriano]'), they referred to the greatness of mind and the talent of the two Italian inventors in Castilian service. What the two had also in common were the institutional conditions under which they realised their projects. Like Turriano, Columbus was forced to make debts among his compatriots to be able to carry out his plan. Throughout their lives as contractual partners of the crown both of them felt the burden of financial responsibility on their shoulders and partly for this reason looked back in anger and despair on what they had achieved. 'As for his own work and skill', an acquaintance of Turriano's reported, 'he desires nothing but what may be of service to Your Majesty [...] He only asks that his creditors may be paid, so as to relieve him from paying further interest, which would otherwise ruin him entirely ('le destruirian absolutamente').'[80]

Columbus, too, felt left alone with the risks of credit business. 'Your Majesties, the Genovese complained in his will, 'have never invested anything, nor had they any intentions of doing so, apart from one million Maravedís, and I had to raise the rest.'[81] In the further course of the expansion the royal counsellors brought the system of self-financing to perfection. In the many contracts they closed with the *conquistadores* and different 'colonial entrepreneurs', it was rarely omitted to establish that the expedition was realised 'a vuestra costa or a vuestra costa y minsión', which is to say at the expense of those who closed the deal with the crown. Should they – which was frequently the case – have no money of their own, they had to try for loans on the private capital market.

Thus, the contractual system burdened the sovereign's contractual partners with significant risks and expenses, as can be seen from Francisco Pizzaro's defiant heraldic motto, that points out the individual's – particularly financial – efforts.[82] Yet, it must not be overlooked, that they, too, could profit by the system, and, indeed, did so. The contract made inventors and discoverers business partners of the crown and

[80] AGS, CSR, leg. 271, fol. 229 (n.d.).
[81] Will from 19 May 1506, in ed. C. Varela, *Cristóbal Colón, Textos y documentos completos. Relaciones de viajes, cartas y memoriales*, 2nd ed. (Madrid: 1984) 361.
[82] *Privilegio de armas*, 13 November 1529: AGI, MP. Escudos y Árboles genealógicos, 7.

guaranteed explicit claims, should the project turn out a success. That there were possibilities of disregarding even contractually accorded rights, is self-evident, but still, the contract gave a certain security and established profitable, very minutely circumscribed claims that could not so easily be withdrawn.

A contract was particularly attractive when granting exclusive rights of exploitation, which meant the exclusion of other 'market participants' for a certain time. In some *asientos* dealing with the opening up of new territories over-seas, it is determined, that no other person, 'nigún mercader ni otra persona alguna',[83] might travel to 'the provinces discovered by the contractual partner in question', nor might anyone trade with them. Technical novelties, too, could thus be protected, so that there was no longer any inducement to conceal them.[84] Thus, the contracts partly fulfilled the functions of a patent.[85] The Spanish crown was excellent at employing, by the means of such and other well-balanced clauses, the resources and innovations of others for their ends, without these others losing their willingness to place their means at the disposal. That, too, was an achievement, maybe even a wonder.

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[83] *Asiento* with Juan Ponce de León, 27 September 1514: AGI, Indif. General 415, L. I, n. 4, fols. 11v.–12v. (quoted in: Milagros del Vas Mingo M., *Las capitulaciones de Indias en el siglo XVI* (Madrid: 1986) 166–168, 167). Cf. the *asiento* with Gonzalo Fernández de Oviedo, 26 June 1523: "vos solamente y quien vuestro poder oviere, y no otra persona alguna"; AGI, Indif. General 415, L. I, fols. 47v.–48v. (quoted in: Milagros del Vas Mingo M., *Las capitulaciones de Indias en el siglo XVI* 199–200, 200).

[84] As compensation for the import of a powerful conveyor- and dehydration technique from the mountainous regions in central Europe, Schedler, the Fugger's representative in Spain, was promised in the *asiento* of 18 September 1553, that during the ten years-term of the contract the king had no right to permit anyone else the utilisation of the imported machines and methods. In the contemporary translation of the Spanish original text it says: 'welches alles ist ain new ding so bißher in disen landen nit gesehen noch durch niemant gemacht worden aus welcher vrsach wird Ir Mt. in zeit der 10jar dies assiento niemants licencia oder erlaupnus geben in disen kunig reichen dergleichen sahen zue machen oder zue brauchen'; FA, 45.6.

[85] On the development of the protection by patent in the late middle ages and the Early modern period: Long P.O., "Invention, Autorship, 'Intellectual Property', and the Origins of Patents: Notes toward a Conceptual History", in *Technology and Culture* 32 (1991) 847–884; – Kurz P., *Weltgeschichte des Erfindungsschutzes. Erfinder und Patente im Spiegel der Zeiten* (Cologne: 2000) 17–225; Lamberini D., "Patents for machines in Grand Ducal Tuscany and the diffusion of technical knowledge in Europe, c. 1564–1640", in Engel G. – Karafyllis N.C. (eds.), *Technik in der Frühen Neuzeit – Schrittmacher der europäischen Moderne*, *Zeitsprünge* 8 (2004) 356–375.

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THE GAP BETWEEN THEORY AND PRACTICE: HYDRODYNAMICAL AND HYDRAULICAL UTOPIAS IN THE 18TH CENTURY[1]

Moritz Epple

I. *Science and Technology in the Age of Enlightenment*

The relationship between scientific and technological activities is precarious, and it was so in different ways in different historical periods. How are these two types of activities embedded in the larger context of the historical events of a particular era? How are scientific ideas formed and developed in specific situations, shaped by concrete theoretical and practical, as well as general scientific and cultural concerns? How, on the other hand, do the efforts of scientific activity contribute to specific solutions of technological problems and thus, in turn, to the cultural and social constellations in which these solutions play a part?

These are far-reaching questions to which there are probably no unequivocal, general answers. Historians know the extremes – from the tightly knit, strongly organized science-technology relations of the 20th century[2] to the no less strongly argued detachment of theory from the practical arts in Plato's conception of science. The early modern period is usually seen as one in which the technical knowledge of practitioners and the 'philosophical' knowledge of the (then) traditional sciences interacted or merged – in optics, in navigation and geodesy, in ballistics and mechanics, in (al)chemical and metallurgical laboratories, and in many other domains.[3] However, the processes joining or bringing

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[1] The first draft of this essay emerged from a talk given to a general audience at the University of Stuttgart in 2003. To some extent the character of this occasion – which called for presenting material for discussion rather than for a scholarly account of own specialized research – has shaped its present form as well. Let me thank the editors of this volume for inviting me to contribute this paper to their collection.

[2] But see Paul Forman's recent, provocative account of the changing hierarchy between science and technology in Forman P., "The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology", *History and Technology* 23 (2007) 1–152.

[3] Edgar Zilsel's studies are a locus classicus of this view, see e.g. Zilsel E., "The Sociological Roots of Science", *American Journal of Sociology* 47 (1942) 245–279. New

together practical experience or interests with theoretical tradition or aims brought their own difficulties and tensions, a historical fact that is strongly reflected in recent historiography. Many justified criticisms notwithstanding, Thomas S. Kuhn's arguments on the Baconian vs. mathematical traditions of early modern science[4] have made clear that between the 16th and 19th centuries, at least, there was no easy marriage between a strongly experimental scientific knowledge inspired by practical experience, on the one hand, and the mathematical disciplines, on the other. Since then, a wealth of new scholarship has explored the history of early modern and modern experiment, including its close relations with instrumentation, and technical knowledge in general.[5] For a long time, the tendency of a substantial part of this literature has been to show that experiments have a 'life of their own', as Hacking's famous slogan goes.[6] As a consequence, the precarious relations of experimental and technical knowledge with the mathematical tradition has been moved to the background of historical interest.[7] On the other hand, recent studies of the early modern mathematical sciences have traced many of their intrinsic convolutions as well as their intertwinings with issues of (natural) philosophy.[8] In their own way, these studies have mostly avoided to investigate the details of the relations between

impulses for the merging thesis come from studies of the material culture of early modern science, see e.g. Klein U. – Lefèvre W., *Materials In Eighteenth-Century Sciences. A Historical Ontology* (Cambridge: 2007).

[4] Kuhn T.S., "Mathematical vs. Experimental Traditions in the Development of Physical Science", *Journal of Interdisciplinary History* 7 (1976) 1–31.

[5] It would not make much sense to enumerate the corresponding literature here. Shapin S. – Schaffer S., *Leviathan and the Air Pump: Hobbes, Boyle and the Experimental Life* (Princeton: 1985) remains a cornerstone. Interestingly, in the translation of Thomas Hobbes' *Dialogus Physicus De Natura Aeris* included in this volume the mathematical sections were omitted.

[6] Hacking I., *Representing and intervening. Introductory Topics in the Philosophy of Natural Science* (Cambridge: 1983).

[7] For the 16th and 17th centuries, Dear P., *Discipline and Experience: The Mathematical Way in the Scientific Revolution* (Chicago: 1995) aims at re-establishing the links between mathematical traditions and empirical elements of scientific knowledge. There remains much to be done, however, even for this period.

[8] For major achievements of this kind, see e.g. Bos H., *Redefining Geometrical Exactness. Descartes' Transformation of the Early Modern Concept of Construction* (New York: 2001), Goldstein C., *Un théorème de Fermat et ses lecteurs* (Paris: 1995), Guicciardini N., *Reading the Principia. The Debate on Newton's Mathematical Methods for Natural Philosophy from 1687 zu 1736* (Cambridge: 1999), or the monumental edition Isaac Newton, *The Mathematical Papers*, ed. D.T. Whiteside, 8 vols. (Cambridge: 1967–1981).

mathematical activities on the one hand, experimental or technical activities on the other.[9]

This mutual disregard of historians leaves the many facets of the history of the *tensions* between experimental and technical knowledge on the one hand, and mathematical knowledge on the other, as one of the white areas in our map of early modern science. This is in stark contrast with the actual role these tensions played in the intellectual culture of the 17th and 18th centuries. Indeed it may be argued that these tensions belong among the core issues that shaped scientific culture during the enlightenment period.[10]

The present essay discusses one fairly well-known area of such tensions in this perspective, i.e., those between hydraulic engineering and emerging hydrodynamic theory of the late 17th and early 18th centuries.[11] While the acknowledgement of a gap between hydraulical practice and hydrodynamical theory has been a historical cliché since a long time,[12] research on the actual interactions across this gap, or on the events happening within it, so to speak, is only beginning to emerge. Olivier Darrigol's and Michael Eckert's recent studies, in particular, have covered new ground in the history of hydrodynamics, while research

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[9] In different ways, Goldstein C., "L'expérience des nombres de Bernard Frenicle de Bessy" *Revue de synthèse, 4e série* 2–3–4 (2001) 425–454, and Greenberg J.L., *The Problem of the Earth's Shape from Newton to Clairaut. The Rise of Mathematical Science in Eighteenth-Century Paris and the Fall of 'Normal' Science* (Cambridge: 1995) are exceptions to this rule. While Goldstein discusses 'Baconian' approaches in number theory, Greenberg investigates the complex scientific field in which the shape of the earth was discussed, ranging from mathematics to practical geodesy.

[10] As will be seen from the following, I am taking my lead, among other things, from studies of enlightenment science such as Hankins T.L., *Jean D'Alembert. Science and the Enlightenment* (Oxford: 1970), and Hankins T.L., *Science and the Enlightenment* (Cambridge: 1985). With respect to the issues discussed here, they still represent valuable starting points for further investigation. For a collection of more recent essays and further guide to the literature, see Porter R. – Lindberg D.C. – Numbers R.L., *The Cambridge History of Science*, vol. 4: *Eighteenth-Century Science* (Cambridge: 2003).

[11] Let me add that my initial interest in hydrodynamics and hydraulics arose not from 18th-century studies but rather from an attempt to better understand the historical background of certain research patterns in 20th-century applied science, in particular, mathematical research connected with major technologies of the the two world wars. As it turns out, the relations between mathematical, experimental, and technological knowledge are no less precarious in this context than in the earlier period.

[12] The classic Rouse H. – Ince S., *History of Hydraulics* (Iowa City: 1957) stated this acknowledgement from the side of hydraulics; work by Clifford Truesdell or monographs such as Szabó I., *Geschichte der mechanischen Prinzipien* (Basel: 1987) reinforced it from the perspective of hydrodynamics.

by Gerhard Rammer addresses the role of hydraulical engineers in the 18th and 19th centuries from new points of view.[13]

The present essay has profited from all these studies. Its main objective is to show that a simple account of an existing gap between theory and practice in the field of hydraulics and hydrodynamics – if understood mainly as a stumbling block for the advancement of science and engineering – would miss an aspect that was crucial for the development of scientific as well as engineering culture in the enlightenment period. This aspect concerns the existence of a *utopia* of mathematical engineering, as it were, a utopia that was fed both by the hopes of hydraulical engineers to mathematize their technical knowledge and by mathematicians or 'geometers', as 18th-century language would have it, to frame a mathematical theory of flows that would enable engineers to improve their technical solutions.

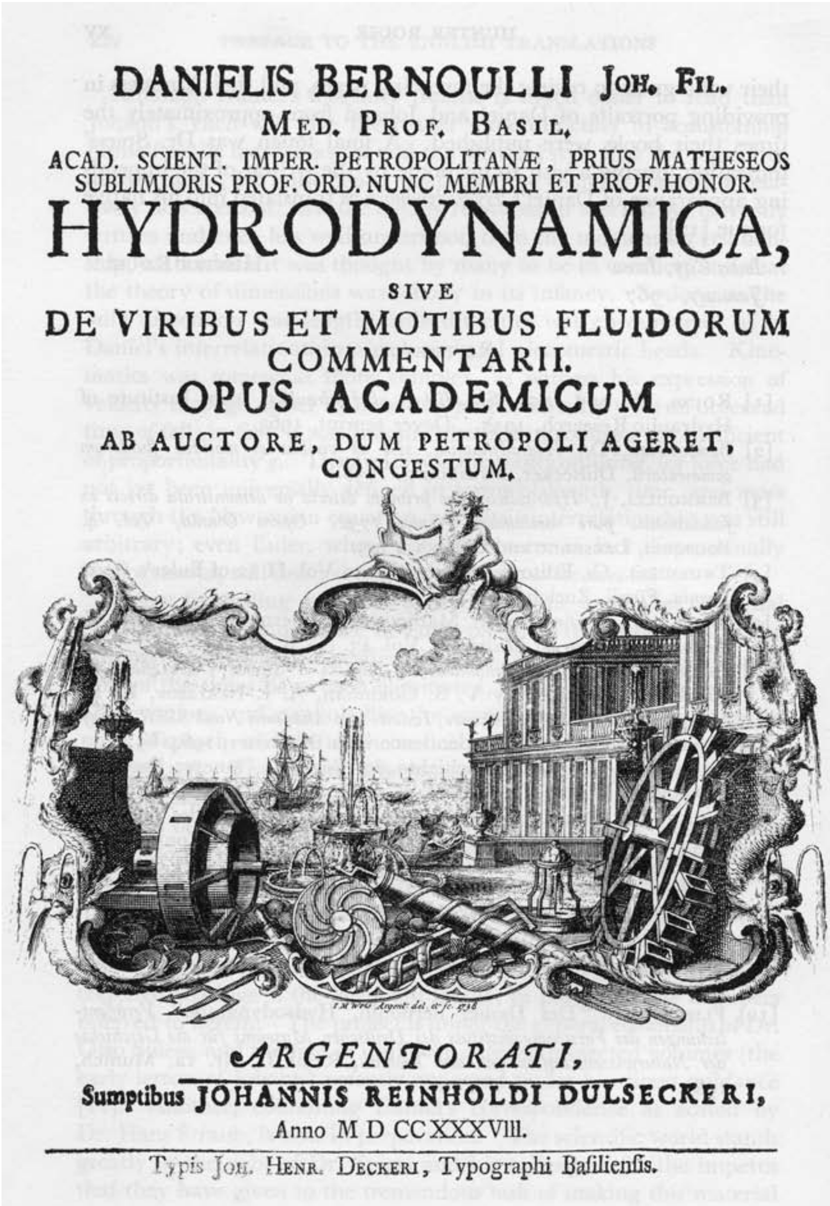
* * *

As is well known, hydrodynamics developed as a mathematical science in the course of the 18th century. The first monograph bearing the title *Hydrodynamica* was printed in the year 1738 and written by the mathematician Daniel Bernoulli, then professor for anatomy and botany in Basel, Switzerland.

As its title page demonstrates to the eye, the context in which Bernoulli situated his work, and in which the emergence of hydrodynamics as a whole must be viewed, was not one of pure thought. The frontispiece contains allusions to ancient and medieval technologies (the Archimedean screw for transporting water upwards, a millwheel); there is also the obvious reference to navigation (in the background) and, at the same time, a contemporary historical reference, a magnificent castle with all sorts of trick fountains. As will be seen in what follows, all these technical and cultural allusions are to be taken quite seriously. The new theory was both developed in a practical context expected to serve practical purposes.

The practical orientation of scientific endeavour is often held to be a general characteristic of scientific culture during the Enlightenment

[13] Darrigol O., *Worlds of Flow. A History of Hydrodynamics from the Bernoullis to Prandtl* (Oxford: 2005); Eckert M., *The Dawn of Fluid Dynamics. A Discipline Between Science and Technology* (Weinheim: 2006). A first account of Rammer's research will appear in Epple M. – Schmaltz F. (eds.), *The History of Fluid Mechanics in Context*, to appear.



DANIELIS BERNOULLI Joh. Fil.
Med. Prof. Basil.
ACAD. SCIENT. IMPER. PETROPOLITANÆ, PRIUS MATHESEOS
SUBLIMIORIS PROF. ORD. NUNC MEMBRI ET PROF. HONOR.
HYDRODYNAMICA,
SIVE
DE VIRIBUS ET MOTIBUS FLUIDORUM
COMMENTARII.
OPUS ACADEMICUM
AB AUCTORE, DUM PETROPOLI AGERET,
CONGESTUM.

ARGENTORATI,
Sumptibus JOHANNIS REINHOLDI DULSECKERI,
Anno M D CCXXXVIII.
Typis Joh. Henr. Deckeri, Typographi Basiliensis.

Fig. 1. Title page of Daniel Bernoulli's *Hydrodynamica* (Basel: 1738), etching.

period. The relationships between technology and science had been put back on the agenda during the period of the rise of the European 'new science' in the 16th and 17th centuries. However, during this period, quite diverse tendencies remained at odds with one another. While an increasing number of craftsmen and artist-engineers made decisive contributions to the expansion of empirical, practice-oriented knowledge of natural phenomena and processes (in the present context one can hardly avoid a reference to Leonardo da Vinci's impressive sketches of hydrodynamic and aerodynamic processes and instruments), numerous other actors of the movement toward a 'new science' aimed strongly at speculative interpretations of both textual knowledge from different traditions and experiences, characterized by a clear preference for *natural philosophy* – or even theology. Leading theoretical scientists of the era like Kepler or Newton, whose juncture of mathematical analysis with natural philosophy in many regards signals a high point of the new science of the 17th century, interpreted their work as a kind of divine service: obtaining insight into the order of nature did not so much mean helping to solve practical problems as obtaining insight into the wisdom of God's presence and activity in the world.[14] Even an instrument such as the microscope could be seen as helping to compensate for the corruption of the senses which had resulted from Adam's expulsion from paradise.[15] And while Robert Merton's studies of the Puritans' motivation for pursuing natural philosophy in England in the 17th century have made plausible that theological orientations could well be connected with an interest in the practical uses of science, the hierarchy of values was clear.[16]

[14] Of course both Kepler's and Newton's writings did adress practical issues as well; for Kepler, his *Nova stereometria doliorum* of 1615 (translated into German just one year later) must be mentioned; for Newton, Book II of his *Principia*. Boris Hessen's famous analysis notwithstanding it may be safe to say, though, that at least for the later Newton a religious orientation was dominating. Similarly, there can be little doubt that Kepler found the unraveling of nature's mysteries and harmonies more intriguing than the improvement of the measurement of casks.

[15] Robert Hooke, *Micrographia* (London: 1665), Preface.

[16] Indeed Merton's "Science, Technology, and Society in Seventeenth Century England", *Osiris* 4 (1938) 360–632, pointed out that besides the Puritan engagement with science there was a second, and highly 'practical' goal for a substantial amount of scientific activity, i.e. the military use of knowledge about natural phenomena. The role this very specific goal played for the development of early modern science, including that of the 18th century, is still in need of further research.

With advancing secularisation of the 18th century, genuine religious orientations became increasingly less significant. The watchword of the period was the social, rather than religious, usefulness of science. This attitude pervades what is perhaps the most successful publication enterprise of the Enlightenment, the French *Encyclopédie*, edited by Jean D'Alembert and Denis Diderot beginning in 1751. Not least for this reason it was more than just a dictionary of learning, namely a "Dictionnaire raisonné des sciences, des arts et des métiers" – a reasoned dictionary of the sciences, arts and crafts. Admittedly, and this brings us closer to the topic at hand, it was not always clear in exactly *what* the social usefulness of science consisted or might consist. This insecurity invited both promises in the future and conflicting proposals.

In the pages of the *Encyclopédie*, D'Alembert, whose contributions to the emergence of hydrodynamics will be discussed below, offered a rather ambiguous account of the utility of the sciences. On the one hand, his *Discours préliminaire* argued as follows: Knowledge of nature should alleviate pain and fear; therefore, the rise of fields of concrete knowledge, such as agriculture and medicine, marks the beginning of scientific endeavour. However, the notable pleasure that thought and knowledge provide the *ésprit* induces the latter to proceed to more abstract sciences, to physical science in general, to mechanics as the most abstract science of bodies and their movement, and finally to all areas of mathematics, ordered by increasing abstraction. Once algebra, the abstract science of quantity, was reached, an inverse chain of successive application of more abstract knowledge to more concrete sciences was possible which, in the end, might help to alleviate human pain and fear. Interestingly, the *immediate* usefulness of scientific knowledge consisted in the pleasure it gave to the mind, diverting it from its ordinary burdens, rather than in an immediate practical or technical use; this latter remained a promise, depending on the successes of applying abstract knowledge to concrete sciences, and, finally, to the arts.

As is well known, this attitude was harshly criticised by Diderot, the principal editor of the *Encyclopédie*. In his *Pensées sur l'interpretation de la nature*, published in 1753, Diderot wrote tersely,

> One of the truths which have been announced in our days with the greatest courage and force, which a good physicist will never lose out of sight, and which certainly will have the most advantageuos consequences, is that the region of the mathematicians is an intellectual world where that which one takes for a rigorous truth absolutely loses this advantage

> when one brings it down to our Earth. From this one has concluded that experimental philosophy would have to rectify the calculations of geometry, and this conclusion has even been admitted by the geometers. But of what use is it to correct geometrical calculation by experience? Would it not be much easier to keep to the result of the latter alone? From which one sees that mathematics, and higher mathematics in particular, does not lead to anything precise in experience; that it is a sort of general metaphysics where all bodies have lost their individual qualities [...].[17]

But for all his criticism of abstract mathematical science, Diderot did not write here as an engineer asking for the contribution of science to the technical arts. Rather he argued as an advocate of the immediate experience of nature understood more aesthetically than technically.

The fact that both sides in this conflict avoided to base their arguments on actual, technical uses of science suggests a fundamental difficulty in the relationship between science and technical practice, characteristic for the 18th century. Indeed, the technological usefulness of the new mathematized science of the era, which was growing at an impressive rate, could only be spoken of seriously in the context of solving concrete problems of technical practice. And that, as we will see, was far from straightforward. The day-to-day relations between theory and practice were involved. Even here, the actual "use" of the one for the other lay, at times, elsewhere than one would naively expect.

II. *Hydraulics*

As is well known, technologies of hydraulic engineering have accompanied human history since the early cultures. Without an artificial water supply, no advanced social and cultural life is conceivable. Fountains, water pipes, systems for bringing water to the surface and mills, yet another central technology of hydraulic engineering, had already been brought to a respectable stage of development in the ancient world and were further improved in the cultures of the Middle Ages. Against this background, the preindustrial Modern era is distinguished not so much by qualitative as by quantitative innovations. French historian Fernand

[17] Denis Diderot, *Pensées sur l'interpretation de la nature, II*, in: Denis Diderot, *Œuvres*, ed. J. Assézat, vol. 2 (Paris: 1875–1877), 9–10.

Braudel estimates, for example, that toward the end of the 18th century over half a million watermills were in operation in Europe, making use of water power in a multitude of technical processes.[18]

Along with the large number of individual mills and similar mechanisms came the systematic coordination of several devices in larger technical facilities. Larger pump works in particular and other water lifting systems, which removed water from mines or aided in the provision of drinking water to private estates, cloisters and, increasingly, to cities as well, were of growing importance. In the cities, waterwheels, pumps, pipe systems and mechanical devices in new configurations came into use on ever larger scale.

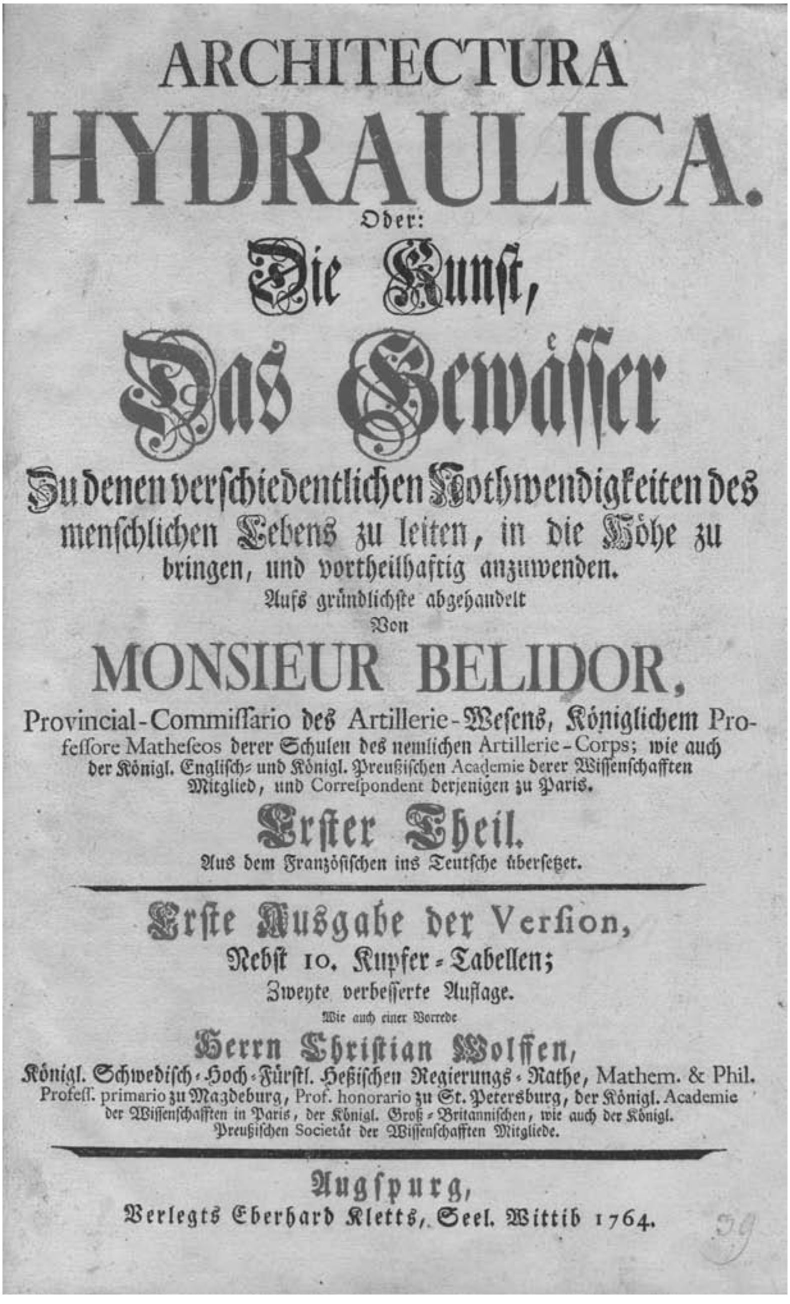
An impression of the multitude of machines employed in the 18th century for such purposes can be gathered from one of the key works of 18th-century hydraulic engineering, the monumental four-volume *Architecture hydraulique*, written by the French military engineer Bernard Forest de Bélidor between 1737 and 1753. Soon afterward, the work was translated into German under the title of *Architectura hydraulica*. A second German edition appeared in 1764; this edition will be used in the following.[19]

A preface written for the first edition by the philosopher Christian Wolff explains that he had suggested the translation.[20] Indeed Wolff opened his preface with an allusion to the fragile usefulness of the science of mechanics. While the *mathematici* had extended and perfected the *theory* of mechanics in recent times, he argued, they were satisfied with the pleasure that new insight provided and did not care much about increasing the "treasures of art" by inventing new machines for the benefit of humankind. This, Wolff continued, was done by

[18] Cf. Paulinyi, A. – Troitzsch, U., *Mechanisierung und Maschinisierung, 1600–1840* (Berlin: 1997) 33.

[19] Bernard Forest de Bélidor, *Architectura hydraulica. Oder: Die Kunst, Das Gewässer Zu denen verschiedentlichen Nothwendigkeiten des menschlichen Lebens zu leiten, in die Höhe zu bringen, und vortheilhaftig anzuwenden* (Augsburg: 1740–1769, 2nd ed. Augsburg: 1764–1767). In order to allow hydraulic practitioners to acquire the work more easily, the first German version was printed in 24 small booklets. In order to allow readers to use different prints or editions, quotations will be referenced in the following to the subdivisions and paragraph numbering of Bélidor's treatise rather than to page numbers. The following scans from this work were all provided by the librarly of the Max-Planck-Institute for History of Science, Berlin.

[20] Christian Wolff, "Vorrede", in: Bernard Forest de, *Architectura hydraulica*, vol. 1, 5.



ARCHITECTURA
HYDRAULICA.
Oder:
Die Kunst,
Das Gewässer
Zu denen verschiedentlichen Nothwendigkeiten des menschlichen Lebens zu leiten, in die Höhe zu bringen, und vortheilhaftig anzuwenden.
Aufs gründlichste abgehandelt
Von
MONSIEUR BELIDOR,
Provincial-Commissario des Artillerie-Wesens, Königlichem Professore Matheseos derer Schulen des nemlichen Artillerie-Corps; wie auch der Königl. Englisch- und Königl. Preußischen Academie derer Wissenschafften Mitglied, und Correspondent derjenigen zu Paris.
Erster Theil.
Aus dem Französischen ins Teutsche übersetzet.

Erste Ausgabe der Version,
Nebst 10. Kupfer-Tabellen;
Zweyte verbesserte Auflage.
Wie auch einer Vorrede
Herrn Christian Wolffen,
Königl. Schwedisch-Hoch-Fürstl. Heßischen Regierungs-Rathe, Mathem. & Phil. Profess. primario zu Magdeburg, Prof. honorario zu St. Petersburg, der Königl. Academie der Wissenschafften in Paris, der Königl. Groß-Britannischen, wie auch der Königl. Preußischen Societät der Wissenschafften Mitgliede.

Augspurg,
Verlegts Eberhard Kletts, Seel. Wittib 1764.

Fig. 2. Title page of the second edition of the German translation of Bélidor, B.F. de, *Architectura Hydraulica* (Augsburg: 1764).

artisans ("Künstler") – who in turn suspected that the mathematicians' theory was little more than a play ("Spielwerck") of the mind which had nothing to offer for the improvement of the mechanical art. Wolff expressed his hope that Bélidor's treatise would contribute to change this mutual misunderstanding.

Reading the fairly thorough descriptions of hydaulic machines and architecture provided by Bélidor (accompanied by precisely scaled and detailed plates), one quickly realizes that Bélidor was driven by one concern in particular: the ineffectiveness of many existing facilities. The desire to perfect ineffective hydraulic engines is perhaps most strongly recognizable in his discussion of water wheels and pump works. In particular, he discussed the pump works in Paris mounted, at the time, under or on the most important bridges across the Seine. As an example, let us consider Bélidor's discussion of the pumps under the bridge of Notre Dame de Paris.

He returns to these pumps several times, discussing them first in the chapter on various types of pumps. Those used under the Notre Dame bridge were instances of combined suction and pressure pumps.

According to Bélidor, this type of pump was among the best of its time. Nevertheless, there were a variety of problems with it, for example when piston and cylinder were not precisely fitted or when, as he wrote, "the leather of the pistons and valves no longer does its duty, or at least does so very poorly, when it begins to dry during warm weather, or when for instance the pumps cannot be kept continually running."[21] In addition, there were difficulties of an entirely different nature, specifically those related to the dimensions of water wheels and their parts, and the parts of pumps such as pistons and pipe systems used to transport the water. It was clear to Bélidor that wrongly dimensioned pipes (like the narrow connecting pipe at the top end of the pump shown in fig. 4) led to large losses of power.

Commenting on the existing pumping facilities with all their faults, he remarked that the high expenditures for such a facility might perhaps be justified for some private individuals (if they could afford such a large expense for a very modest result) but not for public use on a larger scale.[22] At that time, water in Paris was mainly supplied by pipes

[21] Translated from Bélidor, *Architectura hydraulica*, 3. Buch, III. Capitel § 882.

[22] "It should be noted that though such a pump – as may very well befit [the needs of] an individual person – simply cannot be serviceable for the supply of water for an entire city." Bélidor, *Architectura hydraulica*, 3. Buch, III. Capitel § 882.

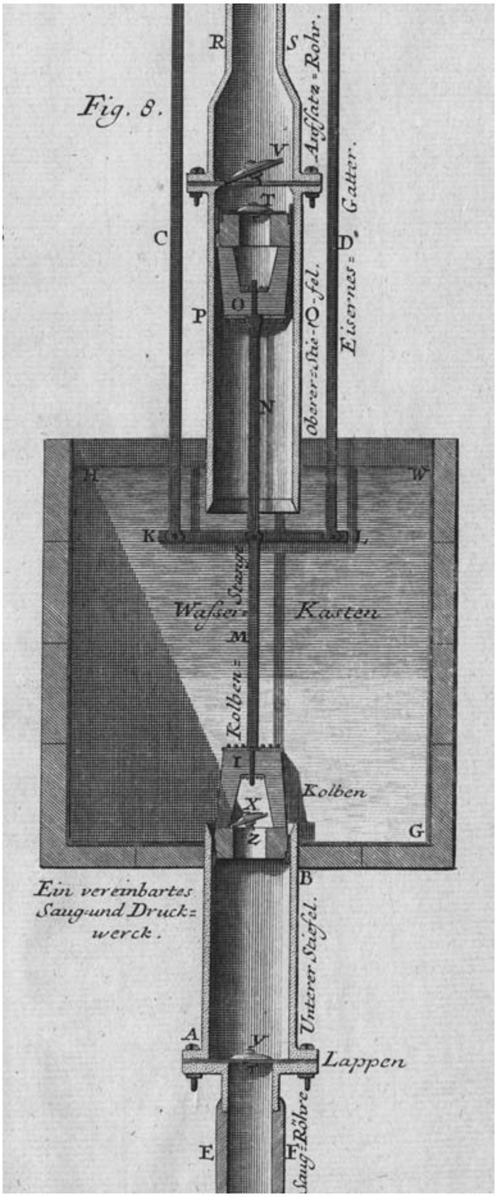


Fig. 3. The type of pump under the Notre Dame bridge, etching from Bélidor, B.F. de, *Architectura Hydraulica* (Augsburg: 1764), 3. Buch, III. Capitel, Tab. 1.[23]

[23] See note 19. The tables of this edition are unpaginated. They can be found in the corresponding sections of the volume.

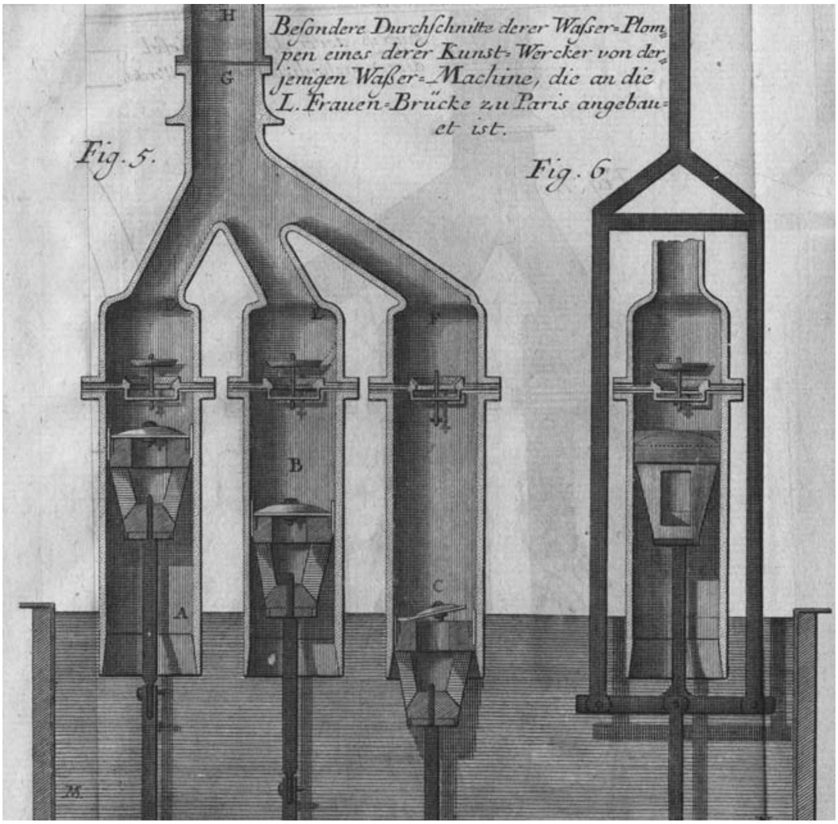


Fig. 4. Notre Dame pumps, old pipe connections, etching from Bélidor, B.F. de, *Architectura Hydraulica* (Augsburg: 1764), 3. Buch, V. Capitel, Tab. 3.

from distant, higher-lying rivers; the water supply, however, threatened to become short, particularly in dry summers. On commission from Parisian merchants and public officers, therefore, Bélidor analyzed the Notre Dame bridge pumping facility and proposed a revision of the entire facility that would lead to better results, he hoped. A new design of the pipe connections bringing together the flows from various pumps was a key element of the new design, many other elements of the pumps were redesigned as well.

The new design principles were given to artisans who then apparently rebuilt the pumps under the Notre Dame bridge.[24]

How could Bélidor frame his suggestions for perfecting the Paris pumps? Doubtlessly, a significant part of his proposal was based on comparative experience. To a large extent, his work was just that: a collection of evidence from many different places and devices that could be used for comparative analysis. His text also shows, however, that he *calculated*. The *Architecture hydraulique* is not only introduced by a detailed review of hydrostatics and hydraulics, as he knew them, it is also supported by lengthy mathematical calculations through many sections of the text, including the analysis of the Notre Dame pumps. Therefore, Bélidor's massive treatise also evidences the active *mathematization* of this area of technology in the 18th century.

Upon closer examination, however, it turns out that many of his calculations were built on sand, so to speak. Despite some remarks to the contrary from later historians, Bélidor did *not* manage to apply the decisive innovations of the hydraulic science of his time – particularly Newtonian approaches to mechanics and the new mathematical methods of analysis. Bélidor followed a Cartesian approach to mechanics. He knew neither the earlier Newtonian concept of force nor Leibniz's or Huygens' concept of living force which predated later notions of work and energy. In the French tradition, Bélidor was familiar with a concept of impulse (in French sometimes called *choc*, sometimes *force du choc* or *quantité de mouvement*) and the parallelogram of impulses, and naturally with the elements of mechanics and hydrostatics going back to Archimedes, i.e. the law of the lever, the principle of hydrostatic pressure (pressure as the weight of a water column on a surface unit),

[24] Bélidor, *Architectura hydraulica*, 3. Buch, V. Capitel § 1148. It is not entirely clear from the text whether these suggestions were actually followed by a rebuilding of the pumps, and if so, whether this was a success.

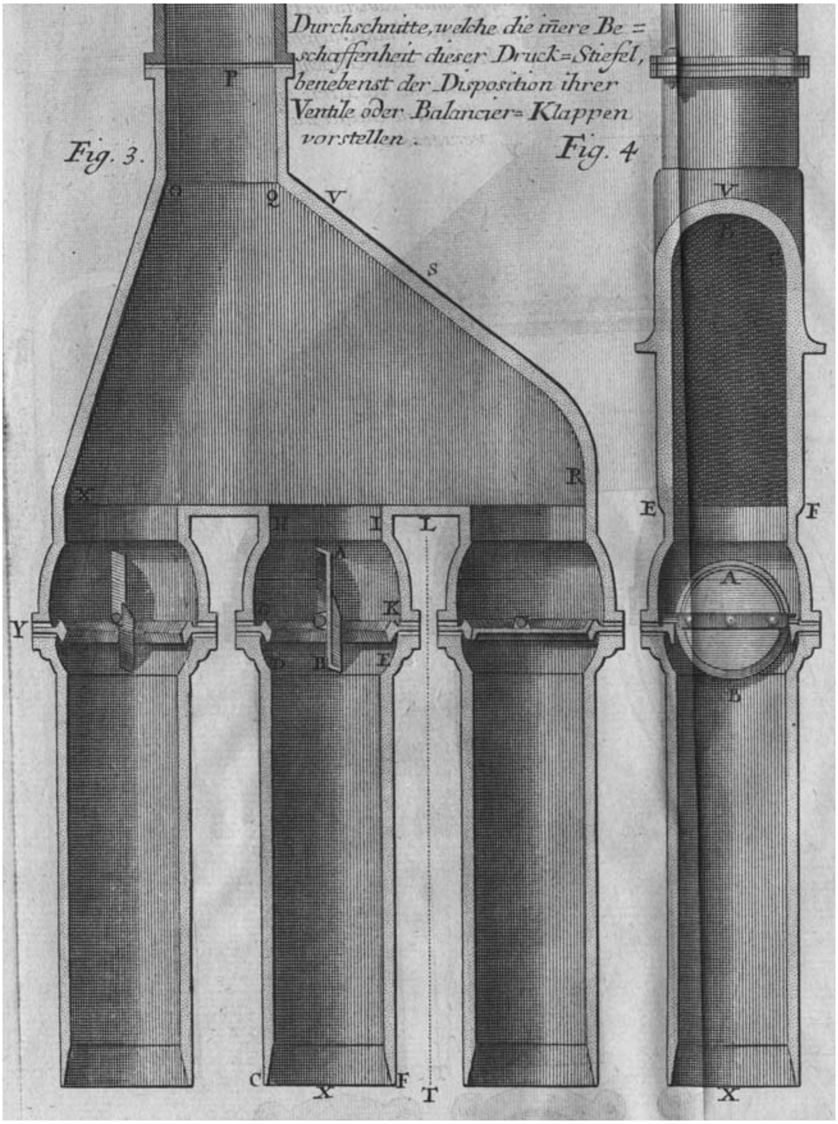


Fig. 5. Notre Dame pumps, new pipe connections, etching from Bélidor, B.F. de, *Architectura Hydraulica* (Augsburg: 1764), 3. Buch, V. Capitel, Tab. 4.

the principle of buoyancy and – decisively – the application of these concepts to relationships in the air, which had become possible through the work of Galilei and his students, especially Torricelli. On the other hand, he knew nothing about new hydrodynamic principles and, more importantly, he did not work in the emerging framework of (Newtonian) analytical mechanics which had not yet been generally accepted throughout France.[25] In addition, his calculations were largely unchecked by a corresponding empirical validation (experimental or otherwise).

Despite the practical insights that formed the basis of Bélidor's critique of ineffective hydraulical facilities and his sensible suggestions for perfecting them it is clear, therefore, that his mathematical calculations models remained inadequate. The promise of mathematics was seductive, but a successful, mathematical art of hydraulic engineering remained a utopia.

The most spectacular machines attracting Bélidor's attention in this context were the great water lifting facilities of the castles of his time. Rich princes and, even more so, the absolutist rulers in late 17th-century and early 18th-century France, and above all, Louis XIV, could afford to have giant pump works erected to supply water to their gardens and palaces, without any concern about their actual technical inefficiency. Bélidor could hardly avoid to include descriptions of these machines in his book. But how did he approach this delicate topic? With remarkable irregularity, as we will see.

As long as hydraulic facilities of foreign kings and princes were concerned, such as the pumps of Nymphenburg in Bavaria (fig. 6), he remained faithful to his general attitude. These water works were severely criticized by Bélidor, who again pointed out the flawed pipe system (which was too narrow) as well as the faulty water wheel.

Yet when Bélidor turned his attention to what, at the time, was the largest water machine in the world, his criticism desisted. This was the water-wheel driven pump work near Marly on the Seine which went into operation in 1685, pumping water for the Versailles castle facilities and the park 163 meters above the level of the Seine.

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[25] Gerhard Rammer (forthcoming), in a more detailed discussion of Bélidor's mathematical approach, points out that Bélidor was relying decisively on earlier work by Antoine Parent and shared the ambiguous physical concepts of the latter.

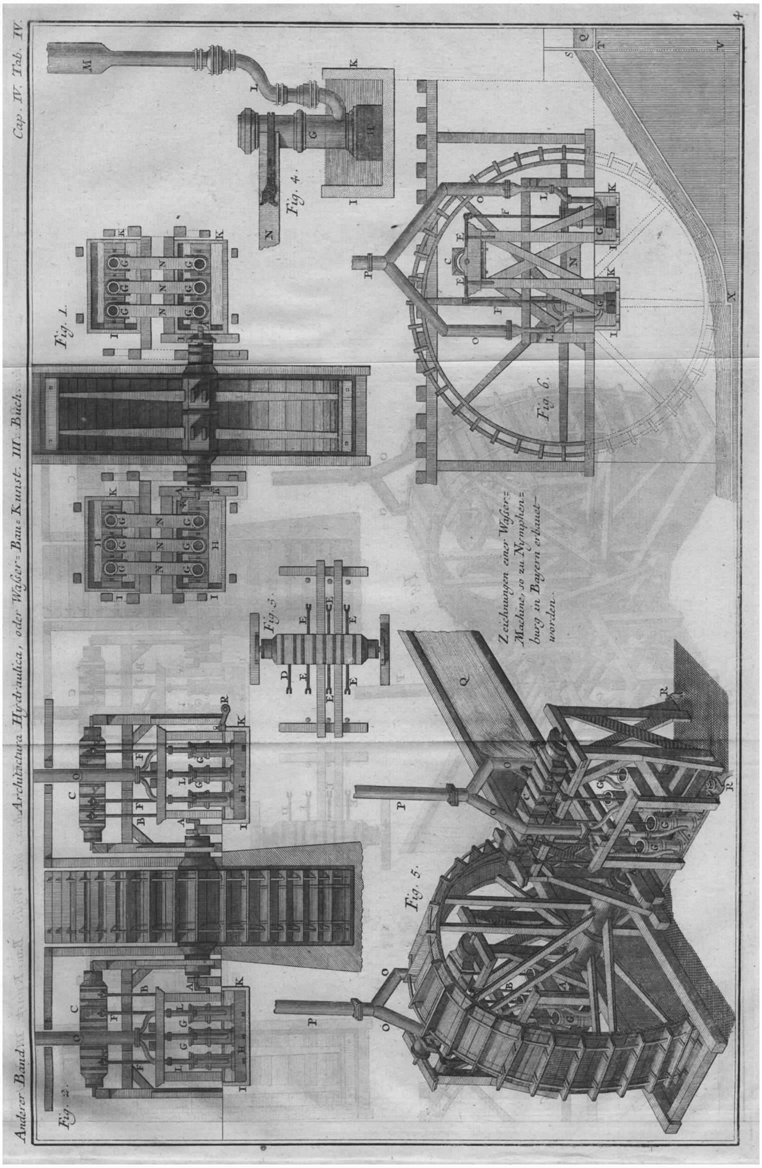

Fig. 6. Pump for the Nymphenburg Castle near Munich, from Bélidor, B.F. de, *Architectura Hydraulica* (Augsburg: 1764), 3. Buch, IV. Capitel, Tab. 4, etching.

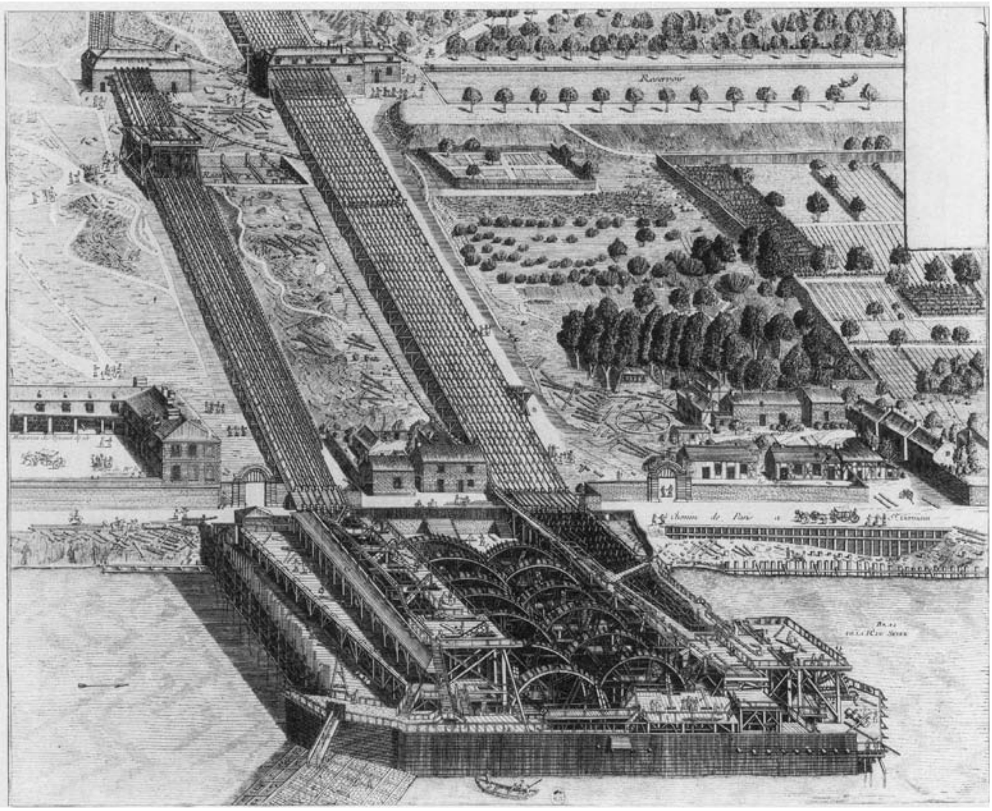

Fig. 7. The works of Marly sur Seine, copperplate, ca. 1700, Paris, Bibliothèque Nationale, reproduced in Paulinyi, A. – Troitzsch, U., *Mechanisierung und Maschinisierung, 1600–1840* (Berlin: 1997) 40.

Fourteen water wheels, each with a diameter of 11 meters, drove a total of 259 pumps by means of a complicated 'Stangenkunst,' i.e. a system of reciprocating rods transferring force. The water was lifted in three stages; reservoirs placed at each third of the pump route of about 1200 meters alleviated the work of the pumps, as well as of the pipes. The structure thus required the construction of a 'Stangenkunst' over two-thirds of the route. Nearly 20,000 tons of metal, most of it iron, was used. At the upper end, an aqueduct led the water into a reservoir from which the castle and gardens of Versailles then received their water. Here is Bélidor's appraisal:

> It does not appear that there at any time has been constructed a machine, of which so great a rumour has spread in the world, as the machine at Marly. It may well be counted among those rare works which have been reserved for His Magnificence Louis the Great. And indeed, it was only appropriate for this monarch to force such a river as the Seine is to leave its natural course, in order to reach the top of so high a mountain as the one onto which it now runs. The poets have made their heroes do wonderful things with the help of Gods: but this great king has found, while excluding all fictions, in his treasure chambers and in the skilfulness of those who put a hand to enlarge his fame, everything that was necessary for realizing his great projects. The situation which he chose in the forest of Marly for building a castle may be taken for one of the most beautiful in the world. In a splendid setting, and in a most charming landscape, nature offered everything that could be desired except water. But how could one have done without the latter in such a place, a place that one wanted to decorate lavishly with everything that the imagination could present as most agreeable and pleasant, as novels have ever magnificiently described such enchanting places? This obstacle would have brought a less powerful prince to give up his plan, however, he wanted to demonstrate that he could bring even the greatest enterprise to a happy ending.[26]

It is hard to believe that Bélidor's fundamental position suddenly changed here. The splendid machine at Marly can hardly have been optimal in Bélidor's eyes. His description and the plates again recorded each detail with precision. For instance, Fig. 8 shows his true-to-scale sketches of the facility with some details of the pumps and the 'Stangenkunst.'

Comparing this machine with those in other places (such as Nymphenburg), an attentive reader would now have expected a similar

[26] Bélidor, *Architectura hydraulica*, 3. Buch, IV. Capitel § 1093.

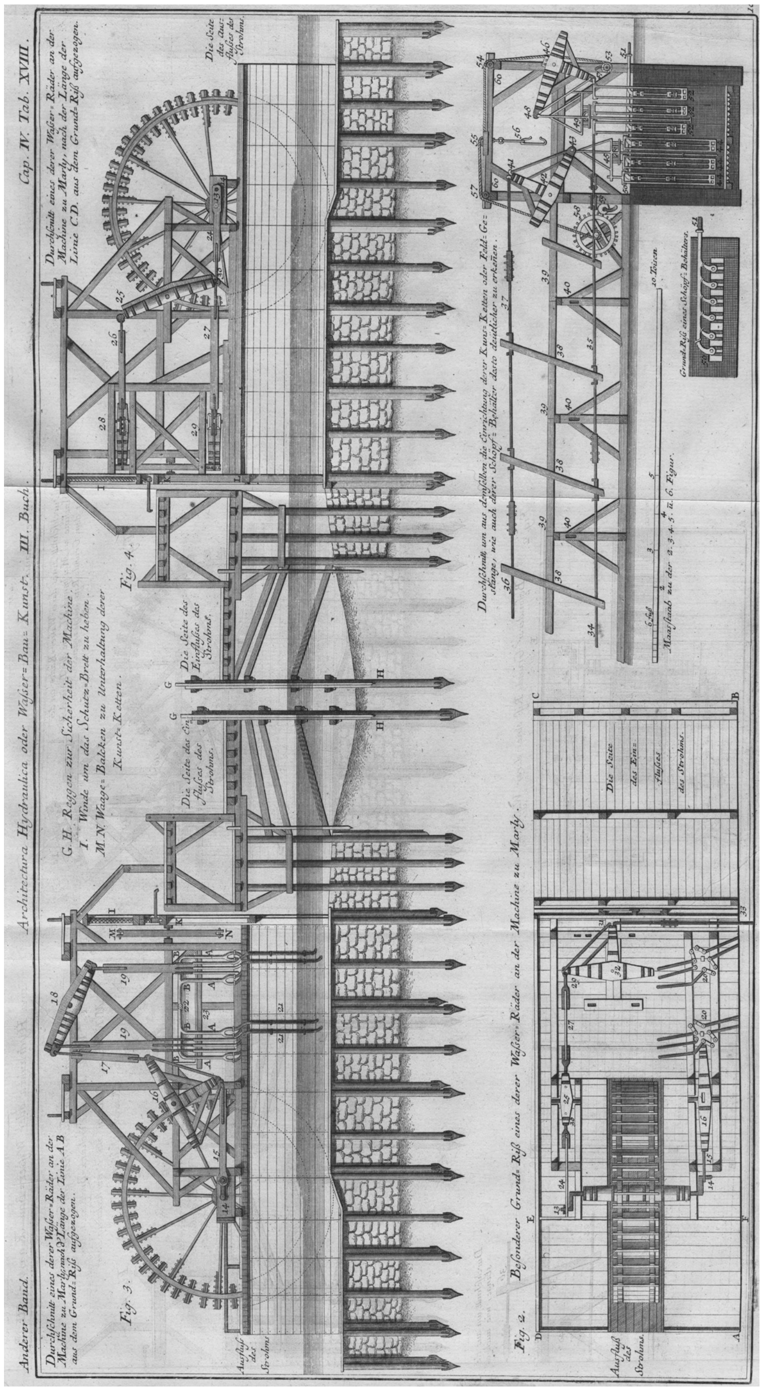

Fig. 8. Partial views of the machine at Marly, etching from Bélidor, B.F. de, *Architectura Hydraulica* (Augsburg: 1764), 3. Buch, IV. Capitel, Tab. 18.

critical discussion rather than the eulogy quoted above. Indeed, the sheer size of the facility and the multitude of active sub-assemblies alone suggests that decreased efficiency was compensated for with absolutist extravagance. I take Bélidor's silence on this point – a point that must have been clear to most of his readers – as the result of obvious political considerations.[27]

The Marly pump works can be seen as a symbol of technology in the culture of Absolutism. In this context, technology serves in the display of splendour. Questions of optimisation and effectiveness, and thus theoretical analyses as well, were of secondary interest compared with the demonstration of wealth; the effect of the technical facility lay as much in the impression it made as in its actual technical achievement. From the more critical point of view of enlightenment scientists, often working in a military and/or administrative bourgeois setting, this was no longer sufficient.

III. *Hydrodynamics*

In about the same time period in which The *Architecture hydraulique* was written, four scientists launched classical hydrodynamics. In 1738, Daniel Bernoulli's *Hydrodynamica* was printed in Strasbourg (it had been given to the publisher already in 1733); in 1743 Daniel's father Johann Bernoulli published his *Hydraulica* in Lausanne and Geneva (including the strange claim that his work had been written even before his son's); in 1744, Jean d'Alembert in Paris contributed his *Traité de l'équilibre et du mouvement des fluides*, adding an important *Essai d'une nouvelle théorie sur la resistance des fluides* in 1752; and in the Memoirs of the Berlin Academy of the Sciences of 1757, two papers by Leonhard Euler, entitled "Principes généraux de l'état d'équilibre des fluides" and "Principes généraux du mouvement des fluides" completed a most remarkable series of treatises aimed at a new mathematical description of fluid flows.[28]

[27] See Brandstetter, T. "Sentimental Hydraulics. Utopia and Technology in 18th Century France", in this volume.

[28] The above, and most of the historical information given in this section, is well known material. For a traditional treatment, see e.g. Szabo I., *Geschichte der mechanischen Prinzipien*, for a more recent discussion compare Darrigol O., *Worlds of Flow*, chapter 1. Still, there is a lot of room for more detailed historical studies of 18th-century fluid mechanics and its contexts. Research presently carried out in connection with the edition of Jean d'Alembert's *Œuvres complètes*, cf. http://dalembert.univ-lyon1.fr/,

The main theoretical result of this development were the basic equations of flows of ideal fluids, i.e. those flowing without internal friction and without compressibility. Euler's second paper gave these equations (Fig. 9, today named after him) as a system of non-linear, partial differential equations which involved the crucial physical quantities on which the new description was based: the local velocity components *u, v, w* at each point with coordinates *x, y, z* of the flow, the fluid density *q*, the local pressure *p*, components *P, Q, R* of an external force and the time *t*, as well as various derivatives.[29]

From this list of quantities it is clear what went into the theory aside from mathematical tools: Newton's basic mechanical concepts (velocities, accelerations, forces, mass, density) and – crucially – the new concept of local pressure in a flowing liquid. The right side of Euler's equations described the acceleration of an infinitesimal element of the fluid, while on the left side he collected the forces acting on this fluid element (per mass); the whole equation thus was 'but' a translation of Newton's mechanical force law into the setting of continuous flow.[30] However, this apparently simple approach was the outcome of a complicated

$$P - \frac{1}{q}\left(\frac{dp}{dx}\right) = \left(\frac{du}{dt}\right) + u\left(\frac{du}{dx}\right) + v\left(\frac{du}{dy}\right) + w\left(\frac{du}{dz}\right)$$

$$Q - \frac{1}{q}\left(\frac{dp}{dy}\right) = \left(\frac{dv}{dt}\right) + u\left(\frac{dv}{dx}\right) + v\left(\frac{dv}{dy}\right) + w\left(\frac{dv}{dz}\right)$$

$$R - \frac{1}{q}\left(\frac{dp}{dz}\right) = \left(\frac{dw}{dt}\right) + u\left(\frac{dw}{dx}\right) + v\left(\frac{dw}{dy}\right) + w\left(\frac{dw}{dz}\right)$$

Fig. 9. Euler's equations for the motion of an ideal fluid, from Euler L., "Principes généraux du mouvement des fluides", *Mémoires de l'académie des sciences de Berlin* 11 (1757) 274–315, on p. 286.

indicates to what extent traditional accounts of the emergence of hydrodynamics are in need of further refinement.

29 The equations were originally published in Leonhard Euler, "Principes généraux du mouvement des fluides", *Mémoires de l'académie des sciences de Berlin* 11 (1757) 274–315, on 286. Note that Euler did not yet use the modern symbols for partial derivatives; in fact all derivatives in the equations are partial derivatives.

30 Here he assumed that internal pressure had only a *normal* effect on the volume element, not an effect through sheer forces (viscosity).

development, as Darrigol rightly reminds us.[31] The brief summary that follows indicates some of the places where hints and objectives from technological domains entered this development.

In the second book of his *Philosophiae naturalis principia mathematica*, published in 1687, Newton had already discussed one of the central problems of the mechanics of continua: the resistance which a body in motion experiences in a continuous medium or vice versa: the force which a body at rest experiences in a flowing medium. The technical context of this problem is fairly clear in Newton's work: On the one hand, he was interested in ballistics and, on the other, in ship construction (in addition, there was the cosmological context of his attempt to refute plenism). Curiously, however, Newton only went halfway in his mathematization of this difficult field. In the end, his continuous media were not continuous at all: he conceived of them as a dense system of fine, elastic particles in empty space. He therefore lacked a concept for local pressure and his results remained, in part, physically problematic. Moreover, Newton's analyses concerning this topic took him into very difficult mathematical territory.

In the 17th century, fluids were usually treated mathematically as continua only in one regard, since the 18th century described by the so-called equation of continuity. This was a mathematical expression of the property that the flow of an incompressible fluid was the faster the smaller the available cross-section of flow, since in equal time intervals, equal amounts of fluid had to pass through a given cross-section. The technical context in which this property was experienced were rivers, canals and pipe systems. It had already been described by Leonardo da Vinci and was exploited by Galileio's colleagues Benedetto Castelli and Evangelista Torricelli in their hydraulical work; indeed they also viewed air as a fluid that rested on the earth. Another important ingredient that came from this Italian tradition of hydraulics was a proportionality describing the velocity of water flowing out of a pipe of a given height: if the water in a pipe was standing at a level h above an opening, the fluid would escape there with a speed v proportional to the square root $\sqrt{h}$ of the filling level. The Italian tradition of hydraulic engineering was soon adopted in France and in other European countries; Torricelli's formula, in particular, was experimentally tested and confirmed many times. Before the advent of hydrodynamics, hydraulical 'theory'

[31] Darrigol O., *Worlds of Flow* 1–4.

essentially consisted of a combination of ancient hydrostatics with fragments of these Italian theories.[32]

The emergence of 18th-century hydrodynamics can be understood as the merging of Newtonian physical concepts with the hydraulic ideas of the ancient and Italian traditions, using mathematical tools that gradually became available in the 18th century. The so-called 'Euler equations' of hydrodynamics for the first time consistently applied Newtonian concepts and laws to fluids described mathematically as continua.

Let us take a closer look at the first step in this merging process, the initial emergence of the concept of a dynamic pressure, in Daniel Bernoulli's *Hydrodynamica*, in order to bring out its background in hydraulical technology.[33]

As in many parts of his work, Bernoulli analysed a particular container-pipe configuration. He imagined a large container with some constantly maintained filling level h, and an escape pipe with a variable

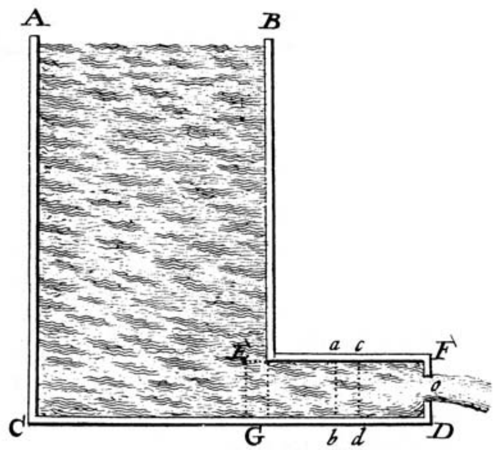

Fig. 10. Daniel Bernoulli's configuration for discussing flow pressure, etching from Bernoulli D., *Hydrodynamics*, transl. T. Carmody – H. Kobus (New York: 1968) 291.

[32] Rouse H. – Ince S., *History of Hydraulics*, chapters 6 and 7.

[33] Daniel Bernoulli, *Hydrodynamics*, transl. Carmody T. – Kobus H. (New York: 1968), here chapter 12, § 5, 291.

small opening *o* at the end which regulated the amount of water escaping through it. According to Torricelli's considerations, the escape velocity through *o* is dependent only on the filling level but not on the area of *o*. The law of continuity then regulates the horizontal speed of the flow in the pipe; the larger *o* the larger would it be.

Both the technical background and the connection to the Italian hydraulic tradition are clear. Bernoulli did not set out to reinterprete the phenomenon in the pipe. As the velocity of the water in the pipe is lower than it could be (i.e., as it is in *o*), the liquid has a *tendency* (Latin *nisus*) to flow faster than it does; this tendency is in balance with a *renisus* at the wall *FD*. *Nisus* and *renisus* lead to the liquid putting pressure on the pipe wall; and, indeed, the less so the greater *o* is in relationship to the cross section of the pipe. Bernoulli calls this tendency to act against the wall the *pressure* [Latin *pressio*] of the pipe flow itself. If another hole *ac* were drilled in the pipe, the water would escape there too at a certain velocity which would likewise be dependent upon *o*. The pressure in *ac* could thus in principle be measured by the level to which a vessel would have to be filled in order to generate precisely this second escape velocity. Additional mathematical analysis of this situation led Daniel Bernoulli to a first version of what came to be known as the Bernoulli Equation.

In this argument, a *hydraulic consideration*, coupled with fairly vague ideas about *forces* (*nisus*), suggested a dynamic (not merely a hydrostatic) concept of pressure. These ideas are still a good distance from those 'simple' Newtonian ones which lay at the basis of Euler's equation, and at the same time their hydraulic origin is obvious. There was still no question of a quantified pressure at each point *inside* a flow but only of a hydraulically quantified pressure on a pipe wall. Moreover, the configuration of motion analysed was essentially one-dimensional and stationary: Bernoulli envisioned the flow ideally as a flow pattern, in parallel layers, that did not change over time. Some attention was given to instationary motions in Johann Bernoulli's *Hydraulica*. D'Alembert then began a two-dimensional analysis of flows in pipes by studying flows in cylindrical pipes with a rotational symmetry. Finally, a fully three-dimensional analysis and the definitive concept of pressure was found in Euler's papers.

In his mathematical analysis of this idealised hydraulical configuration, Daniel Bernoulli made use of yet another principle that must be mentioned here:

> The primary one is the conservation of live forces, or, as I say, the equality between actual descent and potential ascent. I shall make use of this latter term, because it has the same meaning as the first one and finds perhaps a more liberal usage among some philosophers – who indeed are inclined to be upset at the mere mention of *vis viva*.[34]

In this early form of an energy principle, Bernoulli was alluding to the ideas of Leibniz and Huygens, according to which the total sum of the 'live forces' or 'living forces' of mechanical motions – measured for each body set in motion by the product of its mass and the square of its velocity – was preserved. Bernoulli seems to have been inspired by Christian Huygens, who had related a similar principle to the motions of double pendulums.[35] As is well known, a fierce debate about this principle raged until the middle of the 18th century; the philosopher Immanuel Kant even began his career with an essay on this debate. What is more interesting, however, is how Daniel Bernoulli placed and used the principle: Again, he connected it with Torricelli's hydraulical formula and then equated what modern physicists would call today the potential energy of an amount of water brought to a certain height with the moving force or kinetic energy of water escaping from a pipe (for instance in *o* or *ac*): this 'potency' made possible a renewed 'ascent' of the water.

Once more, the technological origin of the metaphor – used as a principle for theorizing – is transparent. Remember the fountains of Versailles and the frontispiece of Bernoulli's text: high-lying water tanks fed the fountains. And vice versa: the moving water of a river provided the power that was used for lifting water. Yet, the relation to water machines is more than simply metaphorical. Reading beyond the basics of *Hydrodynamica* one finds that, on the basis of his energy principle, Daniel Bernoulli turned to exactly the same questions of effectivity that had occupied Bélidor so much.[36] More precisely: it enabled him to indicate a limit for the efficiency of hydraulic machines and to quantitatively assess the effectiveness or ineffectiveness of these machines. If, for instance, some pump works required a certain amount of labour (Daniel Bernoulli quantified this in a very 'modern' way by the product of applied force and distance covered) in a given period

[34] Bernoulli, *Hydrodynamics*, chapter 1, § 18, 12. The awkward translation of the last sentence in this edition has been modified.
[35] Cf. Darrigol O., *Worlds of Flow* 4–7.
[36] See especially Bernoulli, *Hydrodynamics*, chapter 9.

of time, then, in the same period, the machine could rise *at most* the amount of water determined by his energy principle to a given height. An accounting of this type was still not possible for Bélidor.

Bernoulli, who at the time of the composition of his book was still working at the Petersburg Academy of the Sciences, founded by Czar Catherine II, now did what Bélidor had been careful to avoid: he reconsidered the machine at Marly and tried to calculate its (in-)effectiveness. He obtained all the required data from precise descriptions of this marvelous facility, only to conclude that in Marly just 1/56 of the work transferred from the Seine to the driving wheels was actually transformed into potential energy of the lifted water.[37]

IV. *The Limits of Theory: The Resistance of Ship's Hulls and other Bodies*

The military engineer Bélidor was fascinated by questions of effectivity and pursued, in part, mathematical analyses, yet was thwarted by his lack of essential mechanical concepts. His suggestions for improvement remained, in the end, mostly those of an experienced practitioner. Daniel Bernoulli, by contrast, who drew his inspiration from hydraulic engineering, proposed an impressive and, as quickly became clear, promising mathematization. Just as Bélidor, he was focused on questions of technical efficiency. On the basis of his version of a hydraulic energy conservation principle, he managed to give a global quantification of the effectivity of hydraulic machines. But this alone was not sufficient for engineers. Recognizing that the machine in Marly wasted 55/56 of expended energy in pipes, pumps, systems of levers, and bearings did not immediately help to design more economical and functional water lifting works for large cities. The limits of theory were undeniable.

Nor did this change immediately in the further development of mathematical hydrodynamics in the works of d'Alembert and Euler. On the contrary: the gap only became more clearly visible. Any early

[37] Bernoulli, *Hydrodynamics* 206. Daniel Bernoulli's calculation ran allong the following lines: Water from the Seine exerted a force F on each wheel (determined by a formula according to which force was proportional to the area of the wheel paddles and the square of the relative velocity of water flowing past them, see section IV below). The wheel was moved at a certain velocity which resulted in a given distance s covered per day. The total work transferred to the water wheel was thus given by the product Fs. This result (multiplied by the number of wheels in the facility) was now compared to the *absolute potential* of the water lifted to the given height.

hopes of quickly putting hydrodynamics to hydrodrotechnological use were soon dashed. Two factors in particular must be addressed here. One is of a general nature, the other specific; neither is lacking in a certain historical irony.

The general factor can be dealt with quickly. The equations Euler put in final form were among the most difficult epistemic objects of mathematics known at the time. A solution to these non-linear partial differential equations could only be conceived of in very specific cases. Computing tools, such as the 20th century would develop, were not available. However beautiful and interesting the theory might actually have been from a mathematical point of view – because of its intrinsic mathematical difficulties it was only very limitedly useful *at the time* as a theoretical tool for technical problem solving. However, some caution is required in making this assessment. It would be short-sighted to take this as an objection to the mathematical theory itself, as did Diderot, for example. Since the 18th century, Euler's equations have remained the basis of many and even technically crucial areas of hydrodynamics and aerodynamics, and today they are still examined and solved in special cases with great mathematical and computational effort. Their general solution theory continues to belong to the most difficult problems of pure mathematics.

The more specific reason why mathematical hydrodynamics of the 18th century was barely able to cross the boundary into hydrotechnological practice has to do with the problem that had already preoccupied Newton and other scientists of the 17th century, namely the determination of forces which a flow exerts on a solid body immersed in a fluid. The problem was of decisive technical importance on many sides: such forces drove water wheels and windmills, they determined the paths of flying projectiles and the possibilities of ship movements. Questions of optimisation were again of great import. Sometimes these forces had to be maximized (water wheels, wind mills, sails), sometimes they had to be minimized (for projectiles and hulls in the direction of motion). Already in the 17th century, comprehensive experimental attempts at discovering the corresponding laws were undertaken, with more or less success. After a good deal of back and forth, a law crystallized in experimental studies as well as in Newton's theoretical analyses: The force F on a body surrounded by flow was proportional to three factors: fluid density ρ, a characteristic surface A of the body perpendicular to the direction of flow, and the square v^2 of the relative velocity of fluid and

body. Moreover, Newton had found that the proportionality constant (say, c) was dependent on the geometrical form of the body:

$$F = c\ \rho\ A\ v^2.$$

What did the theories of Bernoulli, d'Alembert and Euler have to offer here? The surprising answer was, with only slight exaggeration: Nothing. The new mathematical hydrodynamics could not account for the most important phenomenological law used in practical contexts.

Of course, the hydrodynamicists, and d'Alembert and Euler in particular, tried to tackle this problem with their equations. D'Alembert put great effort into solving this problem, but in the second of the treatises mentioned at the beginning of section III he came to a paradoxical result: According to his fundamental equations of hydrodynamics, the total force on a body immersed in an ideal fluid was equal to *zero*. The core of d'Alembert's elaborate mathematical analysis was that the resulting flow pattern was essentially symmetrical before and after the body, and therefore all local forces of pressure exerted on the surface of a body did cancel each other out. As far as d'Alembert's claims went, they were mathematically correct. So, were the mathematical foundations erroneous then? In a later paper, d'Alembert wrote:

> Admittedly, I do not see how one can [...] satisfactorily explain hydraulic resistance with the help of theory. On the contrary, it appears to me that this theory, treated with the utmost possible rigour, in many cases results in a resistance of absolute zero; a unique paradox which I leave to the geometers for further elucidation.[38]

A discussion of d'Alembert's paradox (suitably rephrased, now a mathematical theorem) still belongs to the stock of all textbooks and histories of hydrodynamics. Modern treatments would emphasize that forces on bodies immersed in a flow arise for two reasons: (a) because surface friction (and viscosity of the fluid) comes into play (the discussion of which indeed required new basic equations, formulated by Navier, St. Venant and Stokes in the 19th century and substantially more difficult than those of Euler); and (b) because even in cases of ideal flow, forces can arise when the flow pattern is not symmetrical – specifically, when

[38] Jean D'Alembert, "Paradoxe proposé aux Géomètres sur la résistance des fluides," 1768, quoted in Szabó I., *Geschichte der mechanischen Prinzipien* 242.

the body is surrounded by a system of vortices (this is another insight of the 19th century, reached by Helmholtz in 1858).

But again caution is needed in assessing the historical situation. Not only was the future unknown, the necessity of coming to grips with the problems of engineering could not be deferred to that unknown future either. In the light of d'Alembert's paradox, scientists of the 18th century could not throw up their arms. They had no choice but to bracket fundamental equations for the time being and to resort to using other tools in their calculations, such as the 17th-century phenomenological law of resistance. Euler did exactly this in his later works whenever he needed to tackle issues of technical design such as that of ship's hulls.[39] At the same time, and in view of the unclear theoretical situation, experimental studies of forces of resistance continued. D'Alembert, for example, became a member of a high-ranking commission put into place by the French government, which examined the resistance of various ship hulls in a towing canal in the 1770s in order to obtain information for the further development of internal shipping.[40] The limitations of mathematical theory were jumped over, as it were, by a pragmatical use of existing knowledge. At the same time, the promise of a mathematization of hydraulic technology remained, unfulfilled and challenging.

V. *The Limits of Practice: The Fountains at Sanssouci*

After having discussed the difficulties faced by the most prominent geometers of the 18th century in bridging the gap to the technical arts, it is now time to turn the tables. For the 'artists', too, came up against their limits and, to put it mildly, for them to have had a bit of theoretical understanding of the processes with which they were confronted would not have hurt. Strictly speaking, that can already be gathered from Bélidor's book. Just as with d'Alembert's paradox in the theoretical realm, there were very curious failures by technical experts as well. Let us return once again to the world of the great rulers, this time to the court of Frederick the Great in Potsdam and the castle grounds

[39] See Euler's "Second Ship Theory": Leonhard Euler, *Théorie complete de la construction et de la manoeuvre des vaisseaux* (St. Peterburg: 1773), Seconde partie, 68.

[40] Details in Rouse H. – Ince S., *History of Hydraulics* 128.

and parks of Sanssouci. The story which needs to be told here is, if you will, also the story of a trifle, namely, the history of the fountains which were to surpass those of Versailles but which, in the end, were never erected, in any case, not in the course of the 18th century. The remaining paragraphs of this section are a brief summary of a much more detailed account by Michael Eckert.[41] His article, which deserves a wide readership, rectifies several earlier accounts of the same events.

As is well known, soon after coming to power in 1740, Frederick II sought to bring French scientific culture to his court. He restructured Berlin's Academy of Sciences and convinced Pierre de Maupertuis, one of France's leading Newtonians and a friend of Voltaire's, to serve as president. From St. Petersburg he brought in Leonhard Euler, who became the director of the academy's department of mathematical and natural sciences. Moreover, he commissioned the construction of a new castle in Potsdam, whose magnificent structure was to do nothing less than cast a shadow over Versailles itself. This castle, Sanssouci, was presented to the public in 1747. A year later, Frederick ordered a new project: the construction of a large water system which was to feed the future fountains of the parks of Sanssouci with water from the Havel River. The central fountain was supposed to shoot water at least 100 feet high, higher than the highest fountain at Versailles.

Initial discussions of the project centered on whether the necessary force could be provided by a steam engine; however, this risky plan was quickly abandoned. The costly alternative of an extensive system of water pipes from more distant heights was also dismissed. Instead, the decision was made to construct a windmill-driven system which, like that in Marly, was supposed to lift the water to a high-lying reservoir (150 feet above the Havel River). Half of the water's route from the Havel River was to be in a canal, from there large pumps were to force the water into the reservoir through an inclining pipe system.

Unfortunately, the king entrusted an architect with no experience in hydraulics and a landscaper who only had experience with very small trick fountains with the planning and carrying-out of the project. Both came from Holland, the land of canals and windmills, which was perhaps the reason for the king's faith in their hydraulic engineering skills. A first attempt in spring 1749 failed miserably. The two men had laid

[41] Eckert M., "Euler and the Fountains of Sanssouci", *Archive for History of the Exact Sciences* 56 (2002) 451–468.

pipes composed of strips of wood fastened together like a barrel with very thin walls between the pumps and the reservoir. On the first test, the water had risen just over half-way when the pipe at the lower end burst. The trusty architects then had thicker pipes constructed. This time, tree trunks were hollowed out and connected to one another. In order to make thick, unbreakable walls, the inside of the pipes were drilled out only very narrowly. Additionally, the pipes were reinforced with massive iron bands. Attentive readers will surmise what happened: Once again the pipes broke on the first attempt. (According to the continuity equation, narrow pipes meant high flow velocities, which according to Daniel Bernoulli also implied high pressures on the walls; also remember that Bélidor repeatedly criticized pipe systems of too narrow dimension.) Infuriated, the king withdrew the Dutchmen's commission.

Between 1752 and 1754, the project was headed by various other engineers. Pipes of an iron-lead alloy were used in the end; yet, still these pipes were quite narrow, apparently for the simple reason that the producer could not supply wider ones. In early 1754, the first demonstration of the works in the presence of Frederick the Great took place. A flood of rain and snow together with an oppressively slow-working pump work managed to fill the reservoir halfway. The day was windy and the central fountain merely rose to half of the required height. After just an hour, the reservoir was empty.

The next hydraulic engineer Frederick hired, after some hesitancy, seems to have been little more than a charlatan. Among other things, he suggested that the water to be lifted from the Havel River should first be directed downwards so that it might gather sufficient momentum for the ascent. The Seven Years War (1756–1763) interrupted all further work and after its end the estimated costs for a new design for the pump works appeared too steep to Frederick. It was not until 1843, nearly a century after the project was initiated, that fountains in the park of Sanssouci were finally constructed using appropriate technical means.

This short history could serve *ad acta* as a nice illustration of technical incompetence and stingy equipping on the part of the king were it not for a sideswipe dealt by Frederick the Great at the moment of his disappointment to Leonard Euler, since long the most important mathematician in his Academy. In 1778, many years after the actual events and twelve years after Euler, disappointed by the king, had returned to the Petersburg Academy, Frederick famously wrote to Voltaire:

> I wanted to erect a fountain in my garden; the Cyclops Euler calculated the power of the wheels in order to make the water rise into a basin, from which it was to fall down again through canals in order to spring into the air in Sanssouci. My mill was geometrically constructed, but it could not even lift a water drop 50 feet up to the basin. Vanity of vanities! The vanity of geometry.[42]

Given that there was absolutely no mention of Euler in the above overview of the construction history, this certainly is perplexing. Rather than the technicians, was the eminent mathematician and hydrodynamicist to blame for the failure of the project? Historians of technology and science have long taken Frederick's letter at face value; Eckert's study shows the opposite was the case. If, in the early phases of the project, there was any critic of the faulty constructions competent in hydraulics then it was nobody else than Euler.

In 1749, after the first failures, Euler began to send letters and memoranda to the king, via the Academy president Maupertuis, in which he clearly listed technical flaws in the plans. To begin with, Euler assumed that metal pipes were to be used. And he began to think – eight years before the publication of his important hydrodynamic memoirs. In October 1749, he presented to the Academy a treatise "Über die Bewegung des Wassers in Leitungsrohren" [On the Motion of Water in Pipes] which above all made one thing clear: instationary processes in pump systems, like the one planned for Sanssouci – as in Marly, water was pushed through the pipes by periodic impulses– increased pressure on the pipes, particularly in the lowest area, considerably above the amount of pressure to be expected from pure hydrostatic considerations.

Euler explained to Maupertuis shortly before submitting his treatise:

> The real cause of this awkward accident [during the first test at Sanssouci] lay solely in the fact that the capacity of the pumps was too great, and as long as it is not considerably reduced […] the machine will not be capable of delivering a single drop of water to the reservoir.[43]

Euler addressed the king directly, using almost the same words, a short time later: "In the state in which they [the pumps] currently can be found, it is quite certain that no drop of water will ever be lifted to the

[42] Translated from Eckert M., "Fountains of Sanssouci" 467.
[43] Translated from Eckert M., "Fountains of Sanssouci" 456.

reservoir and that the force will only be used to destroy the machine and the pipes."[44]

The mathematician, it seems, was the only one who understood what the problems were. However, his petitions to the king, and several further investigations of pipe flow (some of which were clearly addressed to practitioners, went ignored by the emperor and the responsible engineers. No one, for example, took seriously his contention that vertically-arranged pipes were more effective than those running along an inclined slope. In light of these events, Frederick's later letter to Voltaire can only be interpreted as evidence of great techno-scientific naiveté or as intentional malice.

VI. *Concluding Remarks*

Bernard Forest de Bélidor, the military engineer, made extensive calculations to justify his suggestions for improving hydraulic machinery. Jean d'Alembert and Leonhard Euler, eminent 'geometers', made sophisticated arguments and calculations to develop a new branch of mathematics, hydrodynamics. Bélidor's hope, seconded by his German editor, Christian Wolff, was to establish a science of engineering that bridged the gap between mathematical 'theory' and the practical 'arts'. The hope of the geometers, conversely, was to extend the mathematical science of mechanics to continuous fluids in such a way that 'applications' to engineering problems could be made.[45] As we have seen, their uses of mathematics were quite different, and both parties failed to reach their goals. Where Bélidor's mathematization of hydraulic machines was limited by unclear mechanical conceptions and insufficient empirical validation, d'Alembert's and Euler's approaches suffered both from intrinsic mathematical difficulties that were unsurmountable at the time and too strong idealizations of the physical situation that led into discrepancies of their calculations with established empirical evidence.

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[44] Translated from Eckert M., "Fountains of Sanssouci" 457.

[45] The notion of 'application' – of one branch of mathematical sciences to another – was a key notion in the conception of the mathematical sciences put forward in the French *Encyclopédie*. Only in the 19th century, however, the idea of 'applied mathematics' gradually began to replace the earlier conception of 'mixed' mathematics.

Both parties, however, were joined in their utopias. They shared the conviction that a joint perfection of mathematics and the arts was not only possible but actually necessary in order to overcome the inefficiency of existing technology. Even if their backgrounds and intellectual agendas differed, they were allies in this regard. Let us briefly summarize in this light what has been said about the relationship between the practice of hydraulic engineering and hydrodynamic theory in the 18th century.

First of all: The more intelligent representatives on both sides were quite aware that the insights of those on the other side actually were fundamental, and both sides were preoccupied with the issue of optimizing hydraulic machinery. Despite this, the theoreticians of the 18th century did not manage to adequately capture the complexity of existing hydraulic apparatuses. On the other hand, practitioners were often unable to follow even the more concrete suggestions of the scientists; at least not when, as in the case of Sanssouci, neither the artisans nor the king supervising the project recognized the importance of mathematics-based criticisms. The Enlightenment dream of theory and practice going hand-in-hand and the usefulness of mathematical science in particular was not fulfilled in *this* sense.

Still, this phase of the interaction between hydraulics and hydrodynamics remains very interesting from a historical perspective. The first threads were knitted of a fabric weaving together a scientific theory which developed into one of the fundamental theories of physics during the 19th century and remains one of the important areas of mathematical research even today, and an artisanal culture that gradually opened itself toward a conception of engineering taking recourse to the mathematical sciences.[46] For more than a century and a half, in the present case, theory and practice developed at a great distance from one another and, as Gerhard Rammer has emphasized, several intermediate forms of knowledge production – between high mathematics and hands-on practice – emerged; Bélidor's version being one of them.[47]

Something else becomes visible in the complex interaction between hydrodynamics and hydrotechnology in the 18th century: the genesis

[46] This is not to imply that the gap, and the corresonding utopias, did not and do not reoccur in specific places. However, modern techno-scientific culture is based on the dynamical productivity of such transient tensions.

[47] This important point is in the focus of Rammer's research on water wheels, see note 25.

of central scientific ideas in cultural and social contexts. Technology, here, plays the role of a mediating field. We have seen that the key notion of hydrodynamic pressure emerged from hydraulic rather than 'philosophical' considerations. Yet, the context becomes even more obvious in the case of the energy principle introduced by Daniel Bernoulli. In Bélidor's *Architecture hydraulique* we have encountered the social setting in which the problem of the effectivity of hydraulic machines emerged: To the extent that during the Enlightenment the large-scale, civil use of hydraulic technology was taken on the agenda, attention was devoted to seemingly minor details such as low-loss pipe systems etc. The wasteful use of resources which characterized the large works of the princes and kings could not be perpetuated in this new horizon. Changes in the social context of technology thus also created a need for new theorizing.

Scientists such as Daniel Bernoulli responded to this need. His principle of equality of actual descent and potential ascent not only made a decisive contribution to the development of a notion of energy,[48] it also allowed to state a quantitative efficiency criterion that remains fundamental to this day. In fact, the social and cultural context of water lifting facilities and magnificient fountains – including the emerging difference between an aristocratic and a bourgeois approach – played more than the role of creating a demand for new theoretical and technological tools. It actually provided the metaphors and heuristic tools for hydrodynamical *thought*. We have seen that this is valid both for Daniel Bernoulli and for Leonhard Euler when the latter developed his theory of instationary pipe flows. The fountains of Versailles and (even if they were never built) those of Sanssouci, the culture of Absolutism, as well as the more civic orientation of the engineers and scientists of the *lumières* were thus reflected in the conceptual core of the science of their time. This is perhaps the most important immediate effect of the utopias of hydraulics and hydrodynamics in the 18th century.

[48] It seems possible to draw a line from the hydrodynamical considerations of this period through the development of mechanical engineering in France and elsewhere to the period examined in Breger H., *Die Natur als arbeitende Maschine. Zur Entstehung des Energiebegriffs in der Physik, 1840–1850* (Frankfurt am Main: 1982).

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SENTIMENTAL HYDRAULICS: UTOPIA AND TECHNOLOGY IN 18TH-CENTURY FRANCE

Thomas Brandstetter

By the end of the 18th century, the empirical method of Francis Bacon seems to have given way to a more mathematically grounded approach towards natural phenomena. However, in certain circles of French amateur science, there was apparently a revival of what has been called the 'Baconian tradition'.[1] According to Thomas Kuhn, one can identify this habit of thought and practice by three characteristics: first, its reliance on experiments in contrast to mathematics and systematical theory; second, its intimate connection to the world of craftsmen and technical practitioners; and, third, a certain utopian undercurrent. These characteristics, in fact, are useful for describing a cluster of inventions submitted to the French Academy of Sciences in the 1780s. The mathematically inclined contemporaries, and especially the members of the committee of the Academy, however, were quite harsh in their judgement of these machines and their creators. I would like to argue, here, by contrast, that these inventors followed a certain logic not too far removed from contemporary scientific problems, as an examination of the context including the discursive and cultural conditions that triggered the planning and construction of this somewhat fantastic machinery will reveal.

In 1784, the Parisian Academy of Sciences organized a contest for the renovation of the old machine of Marly.[2] This machine had been built in the 1680s to provide the water for the fountains of Versailles, Trianon and Marly; it was the largest device of its kind. Consisting of fourteen waterwheels, each eleven meters in diameter, and a complicated system of levers, it moved more than 220 pumps. Ever since the waterworks went into use, there had been complaints about the expense of its maintenance; by the 1780s the huge machine was perceived as

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[1] Kuhn Th.S., "Mathematical versus experimental traditions in the development of physical science", *Journal of interdisciplinary history* 7 (1976) 1–31.

[2] Brandstetter Th., "'The most wonderful piece of machinery the world can boast of': The Water-works at Marly, 1680–1830", *History and Technology* 21 (2005) 205–220.

a relic of the extravagance and wastefulness of Louis XIV. During the 18th century, numerous projects had been brought forward to improve or replace it; but, apart from a few unsuccessful efforts, nothing had been done to improve the efficiency of the mechanism.

When the Comte d'Angiviller opened the contest, he hoped that the brightest minds in mechanical theory would direct their efforts to the analysis of the machine, and that their proposals could lead to a thorough improvement of its pumps, which by then also provided the drinking water for the surrounding villages.[3] However, his hopes were quickly disappointed. Of more than 100 memoirs that were sent in, only a few came from acknowledged engineers. Most of the papers were submitted by amateurs, and half of them did not even meet the formal requirements of the contest: they were not anonymous, they did not contain calculations and generally rejected the authority of the academicians. Nevertheless, it is this group of inventors with which we will be concerned here, as they proposed the most fantastic projects.

Because the submissions were quite disappointing, the jury refused to choose a winner, and the call for papers was repeated in 1786. Still, the quality of the entries did not improve, and the academicians grew increasingly frustrated, finally closing the contest in 1787 when the winners were announced.[4]

By examining some of the memoirs submitted to both runnings of the contest, it is possible to reconstruct a strain in mechanical inventiveness running against the grain of the grand narrative of the industrialisation and enlightenment rationalisation of technology. To shed some light on its rationale, I will first outline the concept of invention guiding these amateurs. In a second step, I will describe the discourse of the 'economy of nature', for many of the machines which were described, drawn and built as models were *material translations* of this discourse. Finally, I will present some of the plans in greater detail to illuminate the contestants' understanding of technology, according to which technical devices constituted the driving forces behind a thorough reformation of society.

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[3] Letter by d'Angiviller, 2.11.1783, Archives Nationales (Paris) O[1] 1068/460.
[4] *Histoire de l'Académie royale des sciences* (1787/1789) 45.

1. *Sensibility & Simplicity*

At the end of the 18th century, a new concept of invention appeared. It was based upon a sensibilist epistemology and characterised by a strong moral zeal, as well as an emphasis on the individual. The inventor now claimed the role of genuine creator. During the late 17th and early 18th centuries, the invention of a thing or process was held to be less venerable than its perfection, which could not be achieved without collaboration.[5] By the end of the century, however, invention was perceived as an activity that relied entirely on the talent and effort of the individual. The contestant Calles, for example, began his memoir with a rhetorical question: who was responsible for the miserable state of the machine of Marly? Its first builder, Rennequin Sualem 'qui, n'ayant jamais ouvert d'autre Livre que celui de la Nature', or 'ceux qui, après en avoir etudié le Méchanisme dans les ouvrages des Auteurs qui en ont parlé, ont prétendu l'améliorer par les changements qu'ils y ont faits?'.[6]

Here, a gap separates the modest inventor (who had not been corrupted by complicated doctrines) from the scholar, who insisted on the use of abstract theories and thus lacked insight into the true principles of nature. This idea was made popular by Rousseau, whose *Emile* Calles quoted affirmatively: 'Tous est bien sortant des mains de la Nature, tous dégénere entre les mains de celui qui néglige de la consulter.'[7] Such an appreciation of a direct, unmediated knowledge, which preferred the data of the senses to the symbolic language of geometry and mathematics, was rooted in a sensibilist theory of perception gaining influence in the 1750s. Authors like Condillac, Buffon and Diderot ascribed a central role to the emotional reactions accompanying the process of cognition. At the same time, these authors rejected complicated methods and elaborate instruments. They advocated a description of natural

[5] For the high esteem of perfection in contrast to invention, cf. Charles Perrault, *Parallele des anciens et des modernes, en ce qui regarde les arts et les sciences* vol. 1 (Munich: 1964) 75; for the importance of coordinated collaboration, cf. Diderot D., "L'histoire et le secret de la peinture en cire," in *Oeuvres complètes* vol. 10 (Nendeln: 1966) 70.

[6] Calle, "Description et Analyse de la Machine de Marly", Archives de l'Académie des Sciences (Paris), Dossier Prix, Carton 3, Mémoire 33.

[7] Calle, "Description et Analyse de la Machine de Marly", Archives de l'Académie des Sciences (Paris), Dossier Prix, Carton 3, Mémoire 33. As is well known, the first sentence of Emile stated: "Tout est bien, sortant des mains de l'auteur des choses: tout dégénére entre les mains de l'homme". Jean Jacques Rousseau, *Oeuvres complètes IV* (Paris: 1969) 245. Note the shift from god ('auteur des choses') to nature in Calle's version.

phenomena based upon sympathy and willingness to reflect the moral relation of the observer to his object.[8]

According to this theory, the tactile manipulation of objects was privileged epistemologically and morally. For Condillac, the sense of touch was elemental for the relation between the subject and the exterior world. While smells, sounds and colours alone could be perceived as being only modifications of the self, the groping movement of the hand constituted the coherence of the 'moi'.[9] Only when the body hit upon a resisting object, was it able to get an idea of its own limits and constitute itself as a subject. Functioning as a window to the outer world, the sense of touch, therefore, guaranteed the moral sensibility of the subject. Activities not based upon the senses were suspected of being morally dangerous, because they nourished a solipsism which threatened to undermine sociability. Mathematics was especially perilous, for it was based on abstractions independent of sense perceptions.

On the other hand, the groping activity of the artisan was held in high esteem. This can be clearly seen in Rousseau's *Emile*, where the author advised children to work in the shops of craftsmen and to learn to manufacture all the necessary instruments and machines by themselves. Only then would they be able to understand their principles and modes of operation. By way of this argument, the activity of inventing acquired a privileged role in the production of knowledge: 'avant de se servir de ces instruments, j'entends qu'il les invente'.[10] The notion of invention no longer referred to an accidental discovery, but to a genuine creation based on a penetrating comprehension of the fundamental principles of nature. Such knowledge could only be acquired by keen observation and experimentation. Experiment, however, was not meant to be a forceful interrogation of nature (as on Bacons 'rack'), but rather was to be a playful activity that rejoiced in the gentle testing of possibilities.

This epistemology was directed against the 'systèmes' and 'romans' of natural philosophy, which aimed at a comprehensive explanation of phenomena and which did not take into account the moral feelings

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[8] Cf. Georges Louis Leclerc Buffon, *Histoire naturelle, générale et particuliere, vol. 1.* (Deux-Ponts: 1785) 38. My account of the 'sensibilist epistemology' draws on the invaluable book by Riskin J., *Science in the age of sensibility: the sentimental empiricists of the French Enlightenment* (Chicago/London: 2002).

[9] Étienne Bonnot de Condillac, *Traité des sensations* vol. 1 (Paris: 1754) 224.

[10] Rousseau, *Oeuvres complètes* IV 486.

of the observer.[11] Authors like Buffon or Saint-Pierre propagated a sentimental form of description which found its apogee in the primal scene of the unprejudiced, awakening gaze.[12] Natural knowledge should not be acquired by a violent questioning of nature. On the contrary, the methods of research had to be adjusted to the diversity of natural phenomena. By this gentle method, the true 'rapports' between beings were to be discovered, transparent relationships made perceptible without recourse to artificial systems of classification.[13]

These relationships also referred to man: for those able to understand the natural order could also assess the true value of each thing. This did not only apply to natural objects, but also to the products of human ingenuity. By paying attention to the true virtues of artefacts, artists and craftsmen could be liberated from catering to an extravagant lifestyle. While the producers of luxury goods appreciated only things that were cherished in an economy of exuberance ruled by fashion, the simple craftsman would judge things according to their practical value for the whole of society.[14] Therefore, only he who was free of all doctrines and prepared to follow the natural order could be a morally upright inventor, creating simple and useful objects. Learned mechanics, engineers and other experts were not suited for this task. Instead, the ideal inventor was a simple man, like the farmer Crèvecoeur, who modestly reported: 'Sometimes I delight in inventing and executing machines, which simplify my wife's labour. I have been tolerably successful that way.'[15]

Many inventors participating in the Academy's contest appropriated this rhetoric of simplicity and took pleasure in emphasizing their limited knowledge and humble origins. Their pretended naivety also served as grounds for rejecting the formal requirements of the Academy. The painter de Labernadier admitted that the phrasing of his memoirs would not satisfy the commission, but he excused himself by maintaining

[11] Cf. Saint-Pierre J.B.H., *Études de la nature* vol. 1 (Paris: 1791) xii, who opposed the artificical 'systême astronomique' of Newton to his 'théorie naturelle'.

[12] As is well known, the fiction of the awaking statue was the leitmotif of Condillac's *Traité de sensations*. But the theme of the awakening gaze can also be found in Buffon, *Histoire naturelle* 36ff.; Jacques Henri Bernardin de Saint-Pierre, *Études de la nature* vol. 1, 11.

[13] Spary E.C., *Utopia's Garden. French Natural History from Old Regime to Revolution* (Chicago-London: 2000) 197 ff.

[14] Rousseau, *Oeuvres complètes IV* 457.

[15] Crèvecoeur J.H., *Letters from an American Farmer* (Oxford: 1997) 39, a book very popular in France at the time.

that he was a simple man from the province, who lacked any theoretical knowledge.[16] Bassegieardie, the inventor of a siphon pump, said to have made 'ni une science ni un métier' out of the construction of machinery; only occasionally he had dedicated himself to studies.[17] Another participant explained that he had found the working principle of his apparatus while playfully tinkered around with a siphon.[18] Sometimes, this rhetoric led to a self-confident and rebellious attitude. One anonymous contestant justified his refusal to carry out the calculations demanded by the Academy with the dry remark that 'je suis convaincu que vous savez mieux calculer que moi'.[19]

According to sensibilist epistemology, a technical or scientific expert had no exclusive rights for the invention of useful machines. This activity was rather usurped by the amateur: free from artificial doctrines and complicated systems of thought, his enhanced receptivity brought about the inspiration which alone could unveil and harness the hidden principles of nature.

2. *The Intricate Workings of Nature*

In parallel with the conception of the inventor as an original genius, the idea of an 'economy of nature' formed a decisive point of reference for many participants in the contest. The formative texts for this discourse were a couple of dissertations written in the mid-18th century for (and probably by) the naturalist Carl Linnaeus.[20] Many of the concepts articulated there were taken up by sentimental empiricists like Bernadin de Saint-Pierre, Charles Bonnet and others, who called for a merger between experimental inquiry and a sentimental view of nature. Their epistemology whole-heartedly rejected mechanist models of explanation. The authors argued that the investigation of mechanical or 'efficient' causes did not suffice to explain the workings of nature and therefore reintroduced final causes into natural history. Their central explanatory

[16] Archives de l'Académie des Sciences (Paris) Dossier Prix, Carton 3, Mémoire 2 ("Fons fieri gaudet que modo flumens erat").

[17] Archives de l'Académie des Sciences (Paris) Dossier Prix, Carton 3, Mémoire 45 ("Posuit desertum in stagna aquarium et rupem in fontes aquarium").

[18] "Mémoire sur un moyen d'elever l'eau", Archives de l'Académie des Sciences (Paris) Dossier Prix, Carton 3, Mémoire 16.

[19] Letter, 24.1.1784, Archives Nationales (Paris) O^1 1497/544.

[20] Published in Carl Linné, *L'Équilibre de la nature*, ed. C. Limoges (Paris: 1972).

principle was no longer the machine as 'Squélette inanimé & décharné', but rather the 'Corps vivant & respirant, dont on saisit l'économie & dont on admire les proportions'.[21] Their basic assumption was the existence of a dynamic balance which secured cyclical processes at all levels of nature. This idea provided the base for François Quesnay's theorem of the interdependence of the natural and the social economy: in both spheres, not only the same amount, but also the same kind of matter circulated. Agriculture had a special status because it was the only human practice that was capable of producing new qualities of matter. The arts were deemed 'sterile' because they only consumed the objects produced by nature.[22]

To uphold the balance of nature, each object and each living being had to fulfil a specific function. This natural division of tasks had to be mirrored by human society.

> Selon les règles de la nature, nous savons aussi que les *Fonctions* doivent être distribuées de façon à ce qu'un seul n'ait pas à en exécuter un très grand nombre, mais que chacun se voit confier les siennes propres.[23]

Because the 'règles de la nature' prescribed the best possible distribution of tasks, man had only to adopt this plan to reach the best possible state of society. The 'art sociale', the art of organising people, consisted in translating the order of nature into the natural order, that is into positive law, and thereby establish a stable structure in society.[24]

If man would refuse to fulfil this role, nature itself would degenerate. The potentially horrible consequences of such an insubordination had been described by Buffon, who distinguished between 'la nature brute', as it exists before human cultivation, and 'la nature nouvelle'. While wild, uncultivated nature forms a barren landscape where earth is buried beneath its own waste and the circulation of water is clotted in dead swamps, the 'new nature' brought about by man was 'aussi

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[21] François Para du Phanjas, *Théorie des êtres sensibles: ou cours complet de physique, spéculative, expérimentale, systématique et géométrique* vol. 1 (Paris: 1788) x (citation) and vol. 2, 14 (final causes).

[22] Christensen P.P., "Fire, motion, and productivity: the proto-energetics of nature and economy in François Quesnay", in ed. Ph. Mirowski, *Natural images in economic thought: 'Markets read in tooth and claw'* (Cambridge: 1994) 249–288.

[23] Wilcke Ch.D., "La police de la nature", in Linné, *L'Équilibre* 118.

[24] Le Mercier de la Rivière P.-F.-J.-H., *L'Ordre naturel et essentiel des sociétés politiques* vol. 1 (London: 1767) 59.

vivante que féconde'.[25] The important point here is Buffon's description of the task of cultivation as a technical activity. Fire and plough, work and art were necessary to safeguard a harmonious economy of nature. The physiocrat Dupont de Nemours warned that the negligence of agriculture would not only ruin society, but also nature itself: farm buildings would collapse, fields become deserted, weeds would spread and water congest – the once fertile land would have become an extensive swamp.[26]

The discourse of the economy of nature thus provided a frame for the merging of two kinds of knowledge: political knowledge as articulated in physiocratic texts and the physical and technical knowledge of the amateur inventors. Both emphasized the need for holistic reform aimed at optimising natural and social processes to achieve the maximum happiness of the population. The functionalistic logic of this discourse led to a change in the status of technology. In principle, there was no contradiction between instrumental relationships of technical systems and the instrumental relationships of natural beings as voiced by the advocates of an economy of nature. On the contrary, the whole of nature was conceived of as a network of interdependent functions. If they were able to integrate themselves into this plan, this would make an important contribution to the enforcement and maintenance of the natural order. However, traditional mechanical constructions were not perceived as meeting these requirements. The clumsy play of gears, levers and other classical elements of machinery created too much friction and irregularities of movement to be integrated into the economy of nature, which, as we have seen, did not consist of mechanical processes.

The old machine of Marly provided an example of this view: its 'composition monstreuse' was 'la preuve la plus sensible de l'impuissance mecanique', because the power of the river was almost completely lost in a 'forest de bois et de fer'.[27] For this reason, many inventors tried to conceive devices which would do without mechanical elements. This was exactly the aim of amateurs like Trouville, Pellizer and other contributors to the contest of 1784–1786. Their hydraulic and pneumatic gad-

[25] All quotations from Étienne Bonnot de Buffon, "La Nature", in *Oeuvres philosophiques de Buffon* (Paris: 1954) 29–41: 34.

[26] Dupont de Nemours P.S., *De l'origine et des progrès d'une science nouvelle* (Paris: 1910) 26.

[27] Quotation from the report by Lamerville, Conservatoire national des arts et métiers (Paris) B 43/22.

gets were designed to avoid the shortcomings of customary technology. Even if the ambitious projects seemed quite fantastic for their own time, one should speak not so much of utopian but of eutopian machines. In contrast to utopias, eutopias are not defined by their detachment but by an intimate relationship to the world, providing sites for the governing and improvement of processes.[28] As local materialisations of an ideal, universal natural law, where singular circumstances harmonize with the order of the whole, eutopic machines were no longer representations of a mechanistic cosmos, as for instance, clockworks had been for the greater part of the 17th and 18th centuries. Eutopic machines were perceived rather as constitutive elements of a nature characterised by the workings of dynamic forces.

To this end, these devices lacked all elements which, in classical mechanics, had been called 'simple machines'. Instead of using levers, pulleys and gears, the inventors utilized siphons and pneumatic gadgets; their aim was to mobilise the natural forces that regulated the circulation of water and air. Trouville claimed to have found a means by which water could be lifted without pistons 'aussi naturellement qu'elle s'ecoule dans les rivieres'.[29] Bassegieardie stressed the simplicity of his invention, which could do without mechanical components. The movement of his machine would rather imitate the natural laws of hydraulics: 'point de Roues: point d'hommes: point de chevaux [...] la pésanteur naturelle de l'eau, unique principe du mouvement [...]'.[30]

The inventors intended their devices to be more than common machines. They advertised their machines by emphasizing their innovative insights into the workings of natural forces. The new hydraulic and pneumatic gadgets were to be understood as akin to experimental systems: they not only mobilised hitherto unknown forces, but also made them visible. As a result, some inventors wanted to render the machines transparent so as to grant insight into their mode of operation. Renaux offered to construct decisive parts of his device out of glass 'pour que le mouvement soit visible aux spectateurs',[31] Trouville proposed a 'Machine transparante',[32] and Bassegieardie suggested building his device like an

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[28] Vogl J., *Kalkül und Leidenschaft. Poetik des ökonomischen Menschen* (Munich: 2002) 204.

[29] Letter by Trouville, 8.1.1787, Archives Nationales (Paris) O[1] 1498/81.

[30] Bassegieardie, "Mémoire pour la machine de Marly", Archives de l'Académie des Sciences (Paris) Dossier Prix, Carton 3.

[31] Renaux A.J., "Mémoire et Plans d'une nouvelle machine de Marly", Archives de l'Académie des Sciences (Paris) Dossier Prix, Carton 3.

[32] Letter by Trouville, 30.1.1787, Archives Nationales (Paris) O[1] 1498/209.

amphitheatre and surround it with artificial waterfalls.[33] The machines would thus be demonstrations of knowledge, resembling more the instruments of a cabinet of physics than the traditional machinery used for water supply. Exactly like demonstration devices, they would serve to stage the hidden but active principles of nature.

From the early 18th century onwards, demonstration devices were indispensable tools for lecturers in natural philosophy, for they made it possible to illustrate abstract doctrines and theories. By the end of the century, popular mechanical and electrical apparatuses were accompanied by chemical and pneumatic instruments. The analysis of air and the discovery of different kinds of gases, which had been achieved by Cavendish and Priestley, became the rage all over Europe and rendered chemistry a popular undertaking.[34] Because its instruments were simple to produce, this science became a field of research for sensibilist amateurs, who – if they had the guts – could easily reproduce the lecturer's spectacular experiments. However, demonstrations like those of Pilâtre de Rozier, who blew up a hydrogen-filled glass receptacle by ignition, had a serious aim: they visually demonstrated the enormous powers of nature, which normally remained hidden from the senses. Pilâtre, for example, wanted to show that the hydrogen contained in the atmosphere could be ignited by electrical discharges; he thereby explained the phenomenon of lightning and thunder.[35]

The staging of active principles of matter was a *leitmotif* of 18th-century experimental science. At first, it was related to the theological concept of the immanence of divine powers in nature, which Newton had already postulated. According to his theory, 'active principles', (as opposed to mechanical processes), caused gravity and the transformation of chemical substances. As the supporting medium for these principles, Newton assumed the existence of an ether. The circulation of this substance maintained the balance of nature.[36] During the 18th century, the number of powers steadily increased: apart from gravity, there was electricity, light, heat and magnetism. Each of these prin-

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[33] Bassegieardie, "Mémoire pour la machine de Marly", Archives de l'Académie des Sciences (Paris) Dossier Prix, Carton 3.

[34] Crosland M., "The Development of chemistry in the eighteenth century", *Studies on Voltaire and the Eighteenth Century* 24 (1963) 369–441.

[35] Duval C., "Pilâtre de Rozier (1754–1785), Chemist and First Aeronaut", *Chymia* 12 (1967) 99–117.

[36] Heimann P.M., "'Nature is a perpetual worker': Newton's Ether and Eighteenth-Century Natural Philosophy", *Ambix* 20 (1973) 1–25.

ciples were assigned a specific kind of matter. Some, like the gases and vapours, were conceptualised as "normal", substances, which could be weighted and which were subject to the laws of gravity and cohesion, while others, like light, fire and electricity, were thought to be weightless 'imponderables'. Nature was filled with different sorts of fluids, whose existence and reciprocal influence could only be made perceptible by experiments.[37]

While the number of these ethereal substances was disputed, their constitutive function for the maintenance of the economy of nature was accepted. Chemical and physical processes were held to be responsible for the perpetual circulation and transformation of matter. This theory was confirmed by several discoveries, like the renewal of exhaled air brought about by plants, which Priestley stated as a proof for the harmony of the Creation, or the principle of the conservation of matter enunciated by Lavoisier.[38] The atmosphere, which was portrayed as a mixture of gases and different fluids, played an important role in this natural economy. It was thought to be the medium encompassing the mineral, vegetable and animal bodies and man, providing the matrix were the chemical and physical processes necessary for the maintenance of the dynamic balance of nature could take place. Therefore, it was compared to a 'Laboratoire chymique'.[39]

3.

Most scientists believed that hitherto unknown powers were yet to be found in this reservoir of restless fluids. Already the early 18th century saw attempts to render these powers useful for the propulsion of machinery. When in the 1720s a perpetuum mobile was presented in Kassel, Christian Wolff held it possible that an 'invisible, liquid matter' could cause its movement, and Benjamin Franklin once showed that small pinwheels made out of paper could be moved by the electric

[37] Heilbron J.L., *Weighing Imponderables and other Quantitative Science around 1800* (Berkeley: 1993) 5–23.
[38] Schaffer S., "Natural Philosophy and Public Spectacle in the Eighteenth Century", *History of Science* 21 (1983) 1–43; Teich M., "Circulation, Transformation, Conservation of Matter and the Balancing of the Biological World in the Eighteenth Century", *Ambix* 29 (1982) 17–28.
[39] Deluc J.A., *Idées sur la Météorologie* vol. 1 (Paris: 1787) 543.

fluid.[40] But not until the 1780s, when meteorology supplemented by the chemistry of gases had become something akin to a key science, do we see a significant increase in the number of inventions which claimed to use the active powers of the atmosphere to drive machines. In 1784, Leroux presented a perpetual motion machine whose movement he ascribed to the action of a hidden fluid. He granted that a purely mechanical perpetual motion was impossible, but firmly believed that a certain 'élément' he had discovered could sustain the continual movement of any weight.[41]

Some of the hydraulic and pneumatic devices to be used for the replacement of the Marly machine also were designed to draw on the chemical and physical powers of the atmosphere. Guerin de Beaumont drafted a kind of chimney in which a propeller was installed, the movement of which should be caused not only by the rising of warm air, but also by the discharging of hydrogen.[42] In choosing this substance, he related directly to the flying machines which mesmerised France at this time. Beaumont stressed that his invention was a further appliance of the principle that enabled the Montgolfier's baloons. It was known for some time that warm air and 'air inflammable' (hydrogen) had the property of rising into the atmosphere. The balloons were only the most impressive application of this universal principle, which, according Beaumont, could be utilized also for more mundane undertakings.

He thus followed the contemporary discourse which depicted the Montgolfier's flying machines as a kind of applied meteorology. Their invention was understood to be a consequence of the accurate observation of the phenomenon of cloud formation. In meteorological treatises, chemical and physical processes (such as evaporation and the creation of 'vapeurs vésiculaires') were thought to cause a reduction of the specific weight of air and its elevation into higher regions of

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[40] Christian Wolff, *Mathematisches Lexicon* (Leipzig: 1716) 1041; Benjamin Franklin, *Benjamin Franklin's Experiments. A New Edition of Franklin's Experiments and Observations on Electricity* (Cambridge, Mass.: 1941) 174. Franklin later withdrew this interpretation and ascribed the movement of the pin-wheels to 'various circumstances of attraction and repulsion'.

[41] Leroux C.-J., *Traité abrégé d'un mouvement perpétuel, en partie méchanique, en partie élémentaire* (Paris: 1784) 2.

[42] All quotations from Beaumont G., "Moteur universel en matière de mechanique par la force de l'air inflammable de l'eau" and "Mémoire sur la manière de développer toute la force de l'air inflammable de l'eau pour en facile le mobile d'un moteur universel en fait de mecanique", Archives de l'Académie des Sciences (Paris), Dossier Prix, Carton 3.

the atmosphere.[43] Therefore, it was only consistent that devices should turn up which claimed to mobilise this principle for other purposes. After the Academy of Sciences had already confirmed that the balloon could also be used to lift weight, Renaux announced an 'Aërostat le plus parfaitement possible', which could not only fly and lift weight, but also pump water and drive mills.[44] The last two ideas can also be found in the memoir by Beaumont, who tried to raise money for experiments on the use of 'air inflammable' for the propulsion of grain mills. These projects should not be passed off as deceitful schemes aiming at seducing a gullible public. Rather, they were experiments for testing the possibilities of a recently discovered principle of nature, properties of which could be deduced by rational theories about the physical behaviour of gases and vapours.

Other projects show similar efforts towards a mobilisation of the powers of the atmosphere. Among the four memoirs submitted by the indefatigable Renaux was the plan for a gigantic propeller similar to the one by Beaumont.[45] According to its inventor, the movement would be caused by the circulation of air accompanying changes in the weather. Renaux complained that this 'puissance naturelle' had so far never been used, even though it would provide sufficient power not only to lift water, but also to drive mills and other machinery. This was a direct application of the natural economy of the atmosphere, because to fulfil the function as a medium for the balance of nature, atmospheric fluids had to be in constant circulation. Such an 'agitation & mouvement perpétuel dans l'air' was held to be caused by the tides, which, according to contemporary theories, also had an influence on large bodies of air, as well as by the constant vaporisation of water.[46] Also, winds and changes in air pressure and temperature would cause a constant agitation of air, which would be available 'perpetuellement' as a 'force motrice'.[47]

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[43] Deluc J.A., *Idées sur la Météorologie* vol. 1 (Paris: 1787) 16; Cotte L., *Traité de Météorologie* (Paris: 1774) 49.

[44] Renaux A.J., *Prospectus d'Expériences Physico-Mathématiques, à faire par le Sieur A.J. Renaux, du succès de la plupart desquelles il est sûr, étant fondées sur des vérités connues* (1784).

[45] Renaux A.J., "Mémoire et plans d'une nouvelle machine de Marly à proposer au concours des prix Royaux de 1787", Archives de l'Académie des Sciences (Paris), Dossier Prix, Carton 3.

[46] Mann, "Sur les marées aériennes: c'est-à-dire, sur l'effet produit dans l'atmosphère terrestre par l'action du soleil & de la lune", *Journal de physique* 27 (1785) 7–25; Cotte L., *Traité de Météorologie* 39.

[47] Renaux, A.J.: "Mémoire et plans d'une nouvelle machine de Marly".

The allusion to the notion of the 'mouvement perpétuel' is not by chance. For Renaux and other inventors, like the aforementioned Leroux, this was a highly charged term, directed against the mathematical theories of the Academicians. Already in 1775, the *Académie des Sciences* had voted against the acceptance of inventions dealing with perpetual motion, and the engineer Lazare Carnot heaped scorn on those who tried to find 'quelque ressource inconnue, quelque machine qui ne soit pas comprise dans les regles ordinaires'.[48] This outlook was based on the idea of a universal theory of machines and grounded on the irrefutable language of algebra. Sentimentalist inventors, however, viewed this refusal of perpetual motion as nothing more than an arrogant presumption. They thought that nature was full of active powers, and that it would be wrong to maintain that man had already discovered them all.[49] Taking a stance against mathematics (the innovative potential of which they believed to be exhausted)[50] these amateur scientists were convinced that the new discoveries in the fields of chemistry and meteorology testified to the variety of natural powers and demonstrated the difficulty of formulating universal laws.

But the atmosphere was not the only place where hitherto hidden powers were believed to be at work. The inventor Froideveaux drew on a more telluric economy of nature when he presented his 'Machine à feu de nouvelle invention'. To lift the necessary water directly to the aqueduct of Marly, he proposed applying the principle of the 'alembick des distilateures'.[51] Rejecting traditional steam engines (which worked indirectly because they had to move a piston) Froideveaux wanted to vaporise water by means of a gigantic distillation flask. Thereby, it would rise naturally to the top of the hill, where it would condensate and flow down to the reservoirs of the king's gardens. Froideveaux's

[48] Carnot L., "Essai sur les machines en général", in *Oeuvres mathematiques du Citoyen Carnot* (Basel: 1797) 1–124. For the Academy's decision, cf. Hahn R., *The Anatomy of a Scientific Institution. The Paris Academy of Sciences, 1666–1803* (Berkeley-Los Angeles-London: 1971) 145.

[49] Demandres Cl.S., *Observations de l'abbé Desmandres pour servir d'introduction à la connoissance de l'application de sa nouvelle machine à tous les objets les plus essentiels de la Mécanique, avec les démonstrations qui prouvent la vérité des effets qui en résultent* (Rome: 1788) 7.

[50] Glas E., "On the Dynamics of Mathematical Change in the Case of Monge and the French Revolution", *Studies in the History and Philosophy of Science* 17 (1986) 249–268.

[51] Froideveaux, "Mémoire et plans d'une machine à feu de nouvelle invention, pour concourir aux prix Royaux de la Machine de Marly", Archives de l'Académie des Sciences (Paris), Dossier Prix, Carton 3.

invention was more than a simple appropriation of an instrument that was well-used in chemistry and an indispensable part of every cabinet of physics. Dating back to Descartes, the alembic served also as a model for a theory of the water cycle. According to his explanation, the centre of the earth can be seen as a gigantic oven which vaporises the water gathered in subterranean caves. The steam rises through the pores of the earth's crust onto the highest mountains, were it condenses and flows down in rivers, only to seep again into the caves, where the cycle starts anew.[52] The planned site for Froideveaux's oversized distillation flask stressed the reference to this theory: he wanted to dig a deep pit into the mountain, the base of which would be at the level of the river while the noose would reach the aqueduct.

It is true that by the end of the 18th-century, the distillation theory of the water cycle was no longer very popular. Even so, there existed a common consensus that the interior of the earth was, like the atmosphere, a 'grand laboratoire de chimie'. The processes taking place there were thought to be similar to the functioning of chemical and pneumatic machinery. The steam engine is a case in point, because it was perceived as a combination of distilling flask and pump. The author of an article in the *Journal de Physique* described volcanoes as 'machines à feu naturelles' which vaporise the water hidden in the earth, thereby creating a dangerous pressure leading to earthquakes. He proposed to build pits which would serve as safety valves, releasing the backed-up air.[53] The device of Froideveaux, which could also serve this purpose, was therefore not only an embodiment of the inventor's knowledge about the natural economy and its principles, but also a means of supporting this economy. It could rightly claim to be an integral and constitutive component of the natural order.

Another kind of device that was very popular with sensibilist inventors were siphons. They had traditionally been surrounded by a certain aura of mystery. In the 16th and 17th centuries, they were important tools of the *magia naturalis*.[54] By the end of the 18th century, siphons were popular for their simplicity and their lack of complicated

[52] René Descartes, *Oeuvres* vol. VIII, ed. Adam & Tannery P. (Paris: 1996) 243.

[53] C.D.L., "Mémoire sur les volcans et les tremblemens de terre", *Journal de physique* 27 (1785) 81–87. Cf. p. 86 for the notion of the earth as chemical laboratory. For a description of the steam engine as combination of destilling flask and pump, see Para du Phanjas, *Théorie des êtres sensibles* vol. 2, 74.

[54] John Baptist Della Porta, *Natural Magick* (London: 1658) 388.

mechanical elements. In addition, they seemed to integrate themselves harmoniously into the natural circulation of water and air, thus relying on the quiet but effective power of the atmosphere. In contrast to steam engines, Siphons worked without fire, which was thought to be accompanied by noxious gases. The most prolific amongst several inventors[55] of such machines was Trouville. He claimed that his device would be a 'heureuse combinaison de principes non Mecaniques, non Geometriques mais purement phisiques', because its action was to be caused by the pressure of air alone: 'ressort toujours present, toujours actif, toujours entier'.[56] Trouville's construction consisted of a big, airtight container (*grand aspirateur*) into which the water of the river could be fed and released. This container was connected to smaller vessels (*petits aspirateurs*) by means of pipes which were themselves connected to reservoirs. If the water was let out of the *grand aspirateur*, the resulting sub-pressure made the *petits aspirateurs* suck the water out of these reservoirs and piped it into the adjacent higher reservoir. Thus, the water would rise up to the highest peaks all on its own. Trouville strongly emphasized that the operation of his 'hydraulique naturelle, ou l'art d'elever les Eaux sans mécanique' resembled the operations of nature. The tides, in particular, served as a model for his apparatus.[57] This allowed him to understand his apparatus as a constituent part of the economy of nature. The interplay of 'aspiration' and 'expiration' made the workings of the siphon akin to bodily functions (such as the circulation of blood or the respiratory system), which also worked without 'pompes, pistons, rouages, attirails et tumultes mécaniques'.[58] This comparison was not based on the human body conceived of as

[55] Among them Bassegiardie, "Mémoire pour la machine de Marly", Archives de l'Académie des Sciences (Paris) Dossier Prix, Carton 3; Durois de Chémant, Archives Nationales (Paris) O[1] 1497/614; Joseph-Emmanuel de Pellizer Garcia, Archives Nationales (Paris) O[1] 1497/667; Hippolite Reynalt, "Mémoire sur les moyens de perfectionner la machine de Marly contenant la description d'une nouvelle machine plus avantageuse" and "Supplement au mémoire portant pour epigraphe elevaverunt flumina fluctus suos", Archives de l'Académie des Sciences (Paris) Dossier Prix, Carton 3; and the anonymous author of the memoir with the epigraph "Si quid novisti rectius istis, candidus imperti: si non his utere mecum", Archives de l'Académie des Sciences (Paris) Dossier Prix, Carton 3, Mémoire 16.

[56] Letter to d'Angiviller, 30.1.1787, Archives Nationales (Paris) O[1] 1498/209.

[57] Trouville J.B.E.H., *L'hydraulique naturelle, ou la nouvelle science de mouvoir, et d'elever les eaux en tel volume, à telle hauteur et à telle distance, que ce soit, sans pompe, piston, balancier, rouage ni mécanique* (1790) 2.

[58] Trouville J.B.E.H., "Mémoire pour les eaux de Paris", Conservatoire national des arts et métiers (Paris) Dossier B 43/16.

a mechanical model, but on functional analogies: respiration and the circulation of blood were necessary to transport poisonous substances out of and nutrients into the body, thereby maintaining the balance of the natural order. For Trouville, one could recognize such processes in all of nature: 'Toute la nature entiere aspire et expire, même les corps les moins animés en apparance'.[59] If this movement were to cease, nature would become infertile. After the French Revolution, this insight was taken up by the agriculturalist Lamerville, who financially supported Trouville, because he was convinced that his invention would help to regenerate the landscape of the New Nation and thereby increase its physical and moral strength.[60]

4.

With this short overview on some of the machines submitted to the contest for the replacement of the machine of Marly, I hope to have shown that the devices proposed by the sensibilist amateurs were more than the wild ideas of uneducated minds. Albeit mocked and criticised by the Academicians, they nevertheless followed a rationale based upon a sensibilist epistemology which, by the end of the 18th century, had become quite popular in the circles of amateur science. Drawing on the ideas of prominent naturalists, their devices were designed to be constitutive elements of the economy of nature, mobilising active principles of matter to support and maintain its operations. Thereby, they wanted to contribute to a reform of society which, a couple of years later, would find its apotheosis in the rhetoric of regeneration advocated by revolutionaries like the abbé Grégoire. When the spirit of 1789 swept the old institutions away, among them the Academy of Sciences, sensibilist amateurs like Trouville finally could make their voice heard and pick up a career in the new organisations created to support the rights of inventors. But that is a different story [...].

[59] Trouville J.B.E.H., "Mémoire pour les eaux de Paris".
[60] Report by Lamerville to the Comité d'agriculture et commerce, Conservatoire national des arts et métiers (Paris) Dossier B 43/22.

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HISTORY REDOUBLED: THE SYNTHESIS OF FACTS IN LINNAEAN NATURAL HISTORY

Staffan Müller-Wille

Introduction: History, the Matter of Science

It is the mathematical and experimental sciences, rather than natural history, that are usually seen in connection with Francis Bacon's methodological reform of science, in particular, and the Scientific Revolution in general. It is universally agreed, of course, that natural history underwent a rapid development during the sixteenth and seventeenth centuries, due to the large numbers of exotic plants and animals that became known to European scholars in the wake of long-distance trade and colonial exploration. But this development is generally seen as the result of mere fact gathering, conducive to but not constitutive of what we consider to be 'modern' science. Even those few scholars who have been eager to point out the importance of natural history for the Scientific Revolution have tended to reproduce its modern image as a merely empirical, cumulative enterprise that prepared the way towards more theoretically oriented sciences like chemistry and biology.[1]

To some extent, this image of natural history was also shared by those who emphasized the importance of natural history in the seventeenth century. In his *De augmentis scientiarum* (1623), Francis Bacon distinguished two kinds of natural history, 'narrative' and 'inductive', maintaining that the former was 'far inferior in importance' to the latter. The basis for this judgement lay in Bacon's conviction that 'the noblest end of Natural History is to minister and be in order for the Foundations of Philosophy'. 'Narrative' natural history did not serve this end. It was pursued 'for the sake of the knowledge of the things

[1] Levine J.M., "Natural History and the History of the Scientific Revolution", *Clio* 13 (1983) 57–73; Böhme G. – van den Daele W., "Erfahrung als Programm. Über Strukturen vorparadigmatischer Wissenschaft, in Böhme G. – Daele, W. – Krohn W. (eds.), *Experimentelle Philosophie. Ursprünge autonomer Wissenschaftsentwicklung* (Frankfurt am M.: 1977) 185–236; Cook H.J., "Physicians and natural history", in Jardine N. – Secord J.A. – Spary E.C. (eds.), *Cultures of Natural History* (Cambridge: 1996) 91–105.

themselves'. The usefulness of 'narrative' natural history, in other words, was determined intrinsically, solely by the 'pleasure' or 'profit' that its subjects held for the reader, and not by any extrinsic value it had in store for natural philosophy. 'Inductive' natural history, by contrast, was defined precisely by its ability to provide the means to the ends of natural philosophy. As Bacon expressed it, 'inductive' natural history 'is the stuff and material of a solid and lawful Induction, and may be called the nursing mother of philosophy'.[2]

Bacon's distinction of 'narrative' and 'inductive' natural history is interesting, because it shows that he did not believe that the foundations of the new science could be laid through the mere accumulation of particulars. Pursued for its own sake, natural history was more or less worthless. To 'minister and be in order for' natural philosophy, natural history had to give its statements a certain form and a certain order. In a well-known passage of the *Novum Organum* (1620), Bacon compares those who 'only collect and use' to ants, and mere 'reasoners' to spiders, 'who make their cobwebs out of their own substance'. The middle course he recommended was that of the bee which 'gathers its material [and] transforms and digests it'.[3] And in an even more telling metaphor, he compared the state of contemporary, that is mainly 'narrative', natural history with a 'kingdom or state [which] were to direct its counsels and affairs, not by letters and reports from ambassadors and trustworthy messengers, but by the gossip of the street'.[4]

The latter metaphor is so telling, because it calls attention to the fact that Baconian induction involved the ordering of experiences in *written* form. 'Natural and experimental history is so various and diffuse', Bacon maintained in the *Novum Organum*, 'that it confounds and distracts the understanding unless it be ranged and presented to view in a suitable order. We must therefore form *Tables and Arrangements of Instances*, in such a method and order that the understanding may be able to deal with them'.[5] In light of these statements, Bacon's obsession with the classification of 'instances', as well as with different forms of tabulating such instances, which is so conspicuous in the various 'histories' he compiled for the planned third part of his *Instauratio magna*

[2] Francis Bacon, *The Works of Francis Bacon*, ed. J. Spedding – R.L. Ellis – D.G. Heath, 14 volumes (London: 1857–1874) vol. 4, 298.
[3] Ibid. vol. 4, 93.
[4] Ibid. vol. 4, 94.
[5] Ibid. vol. 4, 127; emphasis in the original.

becomes clear.[6] For Bacon, induction was not a psychological process (as portrayed by Aristotle in *Anal. post.* ii, 19) but a process dependent upon the processing of information in texts and diagrams that could only be pursued on a global, historical, and collective scale.[7] As Bacon expressed it in his *Parasceve ad historiam naturalem et experimentalem*, which concluded the *Novum organum*:

> For a history of this kind, as I conceive and shall presently describe, is a thing of very great size, and cannot be executed without great labour and expense; requiring as it does many people to help, and being [...] a kind of royal work [...] [T]he materials on which the intellect has to work are so widely spread, that one must employ factors and merchants to go everywhere in search of them and bring them in.[8]

Bacon's own tendency to organize his histories by textual and diagrammatic means is quite modest, by modern standards.[9] His 'tables of instances' were mainly numbered lists of statements, occasionally interconnected by cross-references. Only rarely do we encounter true tables.[10] It is precisely in this respect, however, that the history of natural history in the seventeenth and eighteenth centuries shows a development going beyond the mere accumulation of facts. As Michel Foucault has shown in his classic *Les mots et les choses*, natural history evolved over this period into 'a general science of order' possessing its own 'area of empiricity', organized by 'taxinomia' or the 'arrangement of identities and differences into ordered tables'.[11] Natural history, in a sense, became a technical affair, accessible only to experts.

Foucault's observation draws attention to two aspects of the Baconian legacy. First, it depended on the development of novel technologies of

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[6] Cf. Malherbe M., "Bacon's Method of Science", in Peltonen M. (ed.), *The Cambridge Companion to Bacon* (Cambridge 1996) 75–98.

[7] Sargent R.-M., "Bacon as an advocate for cooperative scientific research", in ed. Peltonen M. (ed.), *The Cambridge Companion to Bacon* (Cambridge 1996) 146–171.

[8] Bacon, *Works* vol. 4, 251–252. See Solomon J.R., *Objectivity in the Making: Francis Bacon and the Politics of Inquiry* (Baltimore: 1998) for an attempt to situate Bacon's method in 'the symbiotic relation subsisting between the monarch and merchants within the policy and discourse of mercantilism'.

[9] Mary Hesse has argued that this gave rise to the 'frequent mis-interpretation of Bacon as a mere fact-collector"; see Hesse M., "Francis Bacon's Philosophy of Science," in Vickers B. (ed.), *Essential Articles for the Study of Francis Bacon* (Hamden, CT.: 1968) 114–139.

[10] See, e.g., "Historia ventorum" in Bacon, *Works* vol. 5, 146, or 'Historia densi et rari', ibid. vol. 5, 341.

[11] Foucault, M., *The Order of Things. An Archaeology of the Human Sciences* (London: 1970) 67–68.

formalizing and arranging information in printed texts and diagrams. Species catalogues, indices, nomenclatures, and dichotomous tables ('systems'), many of them leaving 'narrative' content aside in the most literal sense, began to form the bulk of publications in natural history. Second, and quite contrary to Bacon's intentions: These innovations led to the emancipation of natural history from the concerns of natural philosophy. Experimenting with new forms of distributing and arranging information, natural history became a discipline pursued for its own sake – now, however, not having particulars as its object, but the general order of nature.[12]

In the following essay, I would like to explore these two aspects of the Baconian legacy – its dependence on the evolution of technologies of writing and the emancipation of natural history from natural philosophy – through the lens of the work of the eighteenth-century naturalist Carl Linnaeus. Linnaeus may seem an unlikely candidate for a study of the Baconian legacy, because conventional histories of biology have portrayed him as an 'Aristotelian' who tried to achieve a classification of living beings through *a priori* reasoning.[13] The first section of this paper will therefore establish Linnaeus' indebtedness to Bacon. The second section will move on to take a look at Linnaeus' classification of the sciences, which shares Bacon's rejection of 'narrative' natural history, but insists that botany, one of the branches of natural history, is nevertheless an autonomous science, not subservient to natural philosophy. The following three sections will then take a close look at three devices used by Linnaeus to arrange written information: species descriptions, tables, and 'histories'. Finally, I will argue that Bacon's legacy must not be understood as the legacy of a particular scientific methodology, but rather as the legacy of a methodological problem: the problem of induction.

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[12] Greene J.C., "The Kuhnian Paradigm and the Darwinian Revolution in Natural History", in Roller D.H.D. (ed.), *Perspectives in the History of Science and Technology* (Norman, OK: 1971) 3–25; Lefèvre W., "Natural or Artificial Systems? The 18th-Century Controversy on Classification of Animals and Plants and its Philosophical Contexts" in Lefèvre W. (ed.), *Between Leibniz, Newton, and Kant* (Dordrecht: 1999) 191–209.

[13] For a detailed critique of this view see Müller-Wille S., Collection and Collation: Theory and Practice of Linnaean Botany, *Studies in History and Philosophy of Biological and Biomedical Sciences* 38 (2007) 541–562.

Bacon, Boerhaave, Linnaeus

Ernst Mayr has called Linnaeus a 'practitioner in scholastic logic' in his influential *The Growth of Biological Thought*.[14] Historical evidence supporting this view, however, is scarce. The only authorities Linnaeus ever quoted on scientific method were Bacon and Herman Boerhaave, and the latter's adherence to Bacon has been well established by scholars.[15] There is much indirect evidence that Linnaeus understood himself as part of the 'Baconian' tradition. Just like Bacon's *Novum Organum*, most of Linnaeus writings were organized by 'aphorisms', short, numbered paragraphs that did not form a consecutive line of argument, but rather a network of independent statements interconnected by cross-references. In one of his unpublished autobiographies, Linnaeus claimed that the main reason natural history had not yet undergone the much needed 'reformation' he had finally been able to achieve, was that 'the science has not been treated *aphoristice*'.[16] There are also a number of passages in Linnaeus work that paraphrase passages from Bacon's *De augmentis scientiarum*. Thus the dedication to the *Hortus cliffortianus* (1737) contains a passage that strongly reminds us of Bacon's description of the 'royal work' of natural history quoted from the *Parasceve* above. 'To hurry to countries far away, to hit one's head against the borders of the world, view the never-setting sun, this is not for the life or even the purse of a single botanist', Linnaeus states in the *Hortus cliffortianus*, and adds: 'The botanist needs global commerce, a library with all the books published on plants, gardens, hot-houses, and gardeners'.[17] And the *Philosophia botanica* (1751) identifies the Renaissance, just as Bacon does, with three 'discoveries': printing, gunpowder, America.[18]

There is also more direct evidence, however, to support the view that Linnaeus relied on Bacon with respect to scientific method. I will briefly discuss two instances in which Linnaeus quoted directly from

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[14] Mayr E., *The Growth of Biological Thought* (Cambridge/MA: 1982) 173.

[15] Klein U., "Experimental History and Herman Boerhaave's Chemistry of Plants", *Studies in History and Philosophy of Biological and Biomedical Sciences* 34 (2003) 533–567.

[16] Carl Linnaeus, *Vitae Caroli Linnaei: Carl von Linnaeuss självbiografier*, E. Malmeström – A.H. Uggla (eds.) (Stockholm: 1957) 137.

[17] Carl Linnaeus, *Hortus Cliffortianus* (Amsterdam: 1737) Dedicatio. George Clifford, a rich merchant and owner of the garden described in the *Hortus cliffortianus*, is thus also referred to as a 'king' in the dedication.

[18] Carl Linnaeus, *Philosophia botanica*, transl. by S. Freer (Oxford: 2003) 17, par. 10. See Bacon, *Works* vol. 4, 114, for a similar enumeration.

Bacon's *De augmentis scientiarum*, and one instance in which he quoted Boerhaave's *Institutiones medicae* (1708).

Linnaeus' *Fundamenta botanica* (1736) opens with a 'preface' that consists in nothing but a quote from Bacon's *De augmentis scientiarum*:

> We know well that a botany (natural history) is extant, large in its bulk, pleasing in its variety, curious often in its diligence; but weed it of fables, quotations, idle controversies, philology and ornaments (which are more fitted for table talk and the *noctes* of learned men than for the instauration of philosophy), it will shrink to a small compass. Certainly it is very different from that kind of history that we have in view.[19]

The quoted passage evinces two things: First, Linnaeus, like Bacon, aspired to reform the science of his time, to 'reform a whole science totally and make a new epoch,' as he stated in one of his autobiographies, with clear religious undertones.[20] Second, Linnaeus shared, at least rhetorically, Bacon's dislike for fables and literary ornament. Thus, in the *Genera plantarum* (1737) he prided himself to have expressed his 'ideas with as few words as possible, caring more for weighty words than pompous and eloquent Latin phrases'.[21] Passages denigrating superstitions, oral traditions, and baroque eloquence abound in Linnaeus work.[22]

The second instance in which Linnaeus made a direct reference to Bacon is in the preface to his *Fauna suecica* (1746), a catalogue of animal species domestic to Sweden. Here, he quotes Bacon's account of the 'first actions of man' in paradise from the first book of *De augmentis scientiarum*. Linnaeus' paraphrase of Bacon's account reads as follows:

> The first actions of man, which he performed in Paradise, comprised two essential parts of science. These are: inspection of the creatures and imposition of names. In order to retain the names (Verul. aug. Scient. 25) he imposed to animals, it was necessary to have distinct characters

[19] Carl Linnaeus, *Fundamenta botanica* (Amsterdam: 1736) Praefatio. Bacon's Latin original can be found in Bacon, *Works* vol. 1, 501. Linnaeus' version differs by small details. In my translation I have relied on Bacon F., *Works* vol. 4, 299. For a detailed account of how Linnaeus was introduced to the Baconian tradition in his student years see Petry M.J., "Introduction", in Carl Linnaeus, Carl von Linnaeus, *Nemesis Divina*, ed. and transl. by M.J. Petry (Dordrecht: 2001) 45–48.

[20] Linnaeus, *Vitae* 146.

[21] Carl Linnaeus, *Genera plantarum* (Leyden: 1737) Ratio operis, par. 25. For an English translation see K. Reeds, "A translation of Carl Linnaeus' Introduction to Genera Plantarum (1737)", Studies in *History and Philosophy of the Biological and Biomedical Sciences* 38 (2007) 563–572.

[22] See, e.g., Carl Linnaeus, *Musa cliffortiana*, transl. S. Freer (Koenigstein: 2007 in press), and my introduction to this edition.

> or traits by which to distinguish species, and to obtain these, through a more accurate examination of individuals, he had to make zoology his business.[23]

This reference to Bacon is revealing, in that it shows Linnaeus' vision of a natural history proceeding by the observation of individual instances, rather than *a priori* reasoning. It is in this sense, also, that the introduction to Linnaeus' *Genera plantarum* quotes Boerhaave's 'fundamental rule' that 'teachers are to proceed from generalities to particulars, while explaining discoveries; inventors, to the contrary, have to pass from particulars to generalities'.[24] The context of this quotation is important: Boerhaaves 'fundamental rule' was offered as advice by Linnaeus to those naturalists who – wrongly in his eyes – had 'assumed various parts of the fructification as a Systematic principle, and with it [...] descended according to laws of division from Classes to Orders all the way down to Species'.

Just like Bacon, then, Linnaeus believed science could only proceed inductively, and that induction was a process taking place on a global, historical, and collective scale. History becomes janus-faced as a result: On the one hand, history was the source of traditions and dogmas that had to be overcome; on the other hand, it was only through an historical movement – a 'total reform', and an ensuing collective effort – that this could be achieved. The next section will show how these two aspects played out in Linnaeus' classification of science.

Science Classified, History Rejected

Walter Baron has maintained, that 'botany and zoology did not exist in the 17th and 18th centuries in today's meaning', but only various 'disciplines which dealt with the "natural bodies" of the three "kingdoms" [of nature] under various aspects', like physics, natural history, and taxonomy or '*Systemkunde*', as Baron called it.[25] As an indication

[23] Carl Linnaeus, *Fauna suecica* (Leiden: 1746) Praefatio. The first two sentences are literal quotes from *De augmentis scientiarum* (see Bacon, *Works* vol. 3, 465). Bacon, in contrast to Linnaeus, goes on to point out that the knowledge acquired through the fall was not natural science but the science of good and evil.

[24] Carl Linnaeus, *Genera plantarum*, Ratio operis, par. 8. The quote is from Boerhaave H., *Institutiones medicae in usus annuae exercitationis domesticos*, third edition (Leiden: 1720) 10, par. 31.

[25] Baron W., "Gedanken über den ursprünglichen Sinn der Ausdrücke Botanik, Zoologie und Biologie", in Rath G. – Schipperges H. (ed.), *Medizingeschichte im Spektrum*.

of this, Baron adduced the titles of books on plants and animals from that time, which only referred to their objects by adjectives or genitive constructions, as in *Historia plantarum, Methodus plantarum, De plantis libri, Isagoge phytoscopica*, or *Philosophia botanica*. The last example, taken from Linnaeus, is intriguing, however, as upon a closer look it turns out to be an instance to the contrary of Baron's thesis: The full title of the *Philosophia botanica* – 'Botanical Philosophy in which the Botanical Foundations are explained' – referred back to Linnaeus' earlier *Fundamenta botanica* (1736), whose subtitle unambiguously spoke of a science of botany: *Fundamenta Botanica quae Majorum Operum Prodromi instar Theoriam Scientiae Botanices per breves Aphorismos tradunt* – i.e. 'Botanical foundations which as a precursor to greater works deliver a theory of the science of botany by short aphorisms'.[26]

That this linguistic elevation of one of the fields of natural history to a science of its own indeed reflects a deep-rooted conviction – and is not just a slip of the tongue – can be seen from Linnaeus' classification of sciences. Based on a distinction of 'elements (*elementa*)' and 'natural bodies (*naturalia*)', Linnaeus proposed a dichotomy of 'physics (*physica*)', dealing with the 'elements', and 'natural science (*scientia naturalis*)', dealing with 'natural bodies', i.e. stones, plants and animals, and thus falling apart into mineralogy, botany, and zoology.[27] The decisive point about this classification, and the point which, in its time, made it a highly idiosyncratic one, was that it accorded to natural history an autonomous, and not subservient, status with respect to 'physics' (by which term Linnaeus referred to natural philosophy). Though 'natural bodies', according to Linnaeus, were composed of 'elements' (i.e. the 'simple bodies' earth, water, air, and fire), their composition remained inexplicable on the basis of the action of these 'elements' alone. For this, Linnaeus suggested, one had to take recourse to principles, which were peculiar to 'natural science' and not reducible to the action of the 'elements'. Linnaeus called these principles 'laws of generation

Festschrift zum fünfundsechzigsten Geburtstag von Johannes Steudel (Wiesbaden: 1966) 9.

[26] Linnaeus, *Fundamenta Botanica*, title page. 'Botanica' is inflected according to the declination used for terms borrowed from Greek in Latin, which gives 'botanices' for the genitive singular. Linnaeus also used the accusative singular 'botanicen'; see Linnaeus, *Hortus Cliffortianus*, Dedicatio.

[27] Linnaeus, *Philosophia botanica* 9, par. 1. See also Carl Linnaeus, "Tanckar om Grunden til Oeconomien genom Naturkunnogheten ock Physiquen", *Kungl. Swenska Wetenskaps-Akademiens Handlinger* 1 (1740) 411–429.

(*leges generationis*)'.[28] They consisted, in the case of living beings, in three general propositions: 1. All living beings are generated by living beings, i.e. there is no spontaneous generation; 2. All offspring resembles its parents, i.e. there is no transmutation; and finally, 3. all offspring exceeds its parents in number.[29] All three 'laws', taken together, constituted Linnaeus' species concept, forming the core of his taxonomic theory and famously formulated as 'there are as many species as different forms produced by the Infinite Being in the beginning, which forms afterwards produced more, but always similar forms according to inherent laws of generation'.[30]

Linnaeus related both 'physics' and 'natural science' in interesting ways to a third science, *oeconomia*, in a programmatic contribution to the first volume of the journal of the Royal Swedish Academy of Science, which Linnaeus had helped to found in 1739. *Oeconomia* was defined as 'the science teaching us the application of the elements [i.e. 'earth, water, air, and fire'] to natural bodies in serving our needs', while 'physics' simply emerged as the science 'rendering the properties of elements' and 'natural science' as the science 'teaching us the knowledge of natural bodies', both together providing the foundation for *oeconomia*.[31] 'All that man can use for his needs', as Linnaeus explained, 'must be at hands on this globe; that is either elements or natural bodies'. Yet 'elements can neither feed nor clothe man', Linnaeus went on, 'for that he must use natural bodies primarily; however, these in themselves are often raw, unless they have been prepared by the elements for the purpose which man enjoys from them'. In other words: Physics provided a general knowledge of tools, or agents of change,[32] while 'natural science', including mineralogy, botany, and zoology, provided a general knowledge of raw materials or resources. Both 'physics' and 'natural science', that is, were 'useful' in the sense that they contributed to the commonwealth through their *technical application*, and the commonwealth

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[28] Carl Linnaeus, *Systema Naturae, sive Regna Tria Naturae systematice proposita per classes, ordines, genera, & species* (Leiden: 1735) Observationes Regna III Naturae, par. 7.

[29] Ibid., par. 1–4.

[30] Linnaeus, *Genera plantarum*, Ratio operis, par. 5.

[31] Linnaeus, "Tanckar om grunden till Oeconomien i naturkunnogheten och physiquen", *Kungl. Swenska Wetenskaps-Akademiens Handlingar* 1 (1740) 411–429.

[32] A similar definition of elements can be found in Herman Boerhaave, *Elementa chemiae* (Leiden: 1732) 30–31.

could only gain through their popularisation.[33] Yet both were oriented towards their own particular object domain and both had to be pursued on their own theoretical grounds if this goal was to be achieved.

Against this background it becomes understandable, why the titles of Linnaeus' main taxonomic works never contained a reference to 'historia' – as so many of his predecessors books did – but only to the entities posed by his taxonomic theory, as *Genera plantarum*, or *Species plantarum*, to name only the most prominent ones. According to students annotations from his lectures on the *Foundations of Botany*, Linnaeus went even further and outrightly rejected the subsumption of botany under anything like 'historia':

> Botany is nowadays not, as she was before, reckoned to be a part of history or physics, which she is in no way. But for older authors she could not be called anything else but history, as they cared for nothing else but to describe her advent. Neither can she be a part of physics, as natural science is in no way connected with physics. So since one does not only know about the advent of botany, and what only belongs to history, but also has started to look for other properties of plants, she is a science.[34]

This remarkable passage describes a two-fold change resulting from the elevation of botany (one of the 'natural sciences') to an autonomous science alongside 'physics', a change replete with inherent conflict. On the one hand, it appears, as if the information on particular plants amassed by the age old tradition of *historia naturalis* has turned out to be worthless, as if all previous experience had completely and radically been abrogated by Linnaeus' 'total reform'. On the other hand, however, it appears that the contents of that older 'natural history' pertained to the 'advent' (*uppkomst*, a word with the dual connotation of beginning and development) of that very same science. If the former aspect is not to be rejected as implausible – how could even Linnaeus, who was notoriously self-confident, have done without the information contained in older 'natural histories'? – and the latter not as impossible – how

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[33] Linnaeus' article in the academy's transactions was accompanied by an article of the famous engineer Christopher Polhem, titled 'On the so-called elements' use and effect in mechanics'. On the utilitarian context of Linnaean natural history and its eighteenth-century legacy see Meyer, T., "Die 'Anleitung zur Technologie' (1777) von Johann Beckmann und ihr historischer Kontext. Technologische Bildung in modernisierender Absicht?", in Engel G. – Karafyllis N.C. (eds.), *Technik in der Frühen Neuzeit – Schrittmacher der europäischen Moderne*. Special Issue of *Zeitsprünge* 8 (3/4) (Frankfurt am Main: 2004) 442–465.

[34] Carl Linnaeus, Föreläsn. öf. Fundamenta Botanica, Uppsala Universitets Bibliothek, Linnaeusrummet, Sign. D75:d 4–5.

should older 'natural histories' engage in telling the story of the rise of a science yet to come? – the only plausible interpretation remaining is that Linnaeus envisioned a science of botany, whose essence consisted not in a circumscribed area of objects but in a tradition of scientific activities sustaining and transcending itself in one and the same movement. That such an interpretation is indeed possible can be shown by taking a close look at how Linnaeus himself assembled and organised empirical observations on plants within his botany. In the following three sections, I will focus on three ways Linnaeus did just that: description, tabulation, and 'history', the latter expression taking on a new, temporal sense.

Description

Though Linnaeus rejected 'natural history' as a term adequate for the description of his taxonomic enterprise, it appears at a quite prominent place: In 1736 Linnaeus published a folio leaf (fig. 1) bearing the title 'The Method of Carolus Linnaeus, Swede, in conjunction with which the Physiologist can put in order accurately and successfully the History of any Natural Subject'.[35] Basically, it presents a hierarchical scheme of headings and subheadings stating the order of categories under which various predicates assignable to a given stone, plant, or animal should be subsumed: First, the 'names', with a 'chosen name', its synonyms and its etymology; second, 'theory', i.e. the various taxonomic groups (classes, orders) under which the stone, plant, or animal in question falls; third, the 'genus' to which it should be assigned according to various differentiating characters; fourth, its 'species' with a full description of its morphology and a discussion of the characters that distinguishes it from other species; fifth, the 'attributes (*attributa*)', including information on ecology ('season, place, food') and 'anatomy'; sixth, the 'uses' in the human economy and medicine, and finally, seventh, 'literary matters', i.e. information on cultural traditions. In the *Philosophia botanica* and the later editions of the *Systema naturae* Linnaeus developed and refined this scheme and provided a terminology (*termini artis*) to be used with it. The

[35] Carl Linnaeus, *Methodus Juxta Quam Physiologus Accurate & Feliciter Concinnare Potest Historiam Cujuscunque Naturalis Subjecti* (Leiden: 1736). The English translation quoted here and in the following has been provided, together with a useful and insightful commentary, by Cain A.J., "The 'Methodus' of Linnaeus", *Archives of Natural History* 19 (1992) 231–250.

Methodus, in short, was designed as a measure for giving any natural history account an organized and concise form. 'All that he elaborated', as Linnaeus said of himself, 'he wrote short and powerful. Everywhere he showed himself as a born *Methodicus*'.[36]

Arthur J. Cain has shown that Linnaeus' *Methodus* stood in a tradition reaching as far back as Aristotle's *Historia animalium*, a tradition which was continued and developed by Conrad Gesner, Ulysse Aldrovandi, John Jonston, and John Ray in the Renaissance and Early Modern periods. Against these forerunners, however, Linnaeus' scheme showed a remarkable and important shift in emphasis. While in Aldrovandi, for example, 9 out of 39 headings refer to cultural tradition (including *mystica, moralia, hieroglyphyca, historica, praesagia, proverbia, numismata, epigrammata, epitheta*),[37] the main bulk of Linnaeus' *Methodus* concerns taxonomic matters (in the sections headed *Theoria, Genus*, and *Species*) with only the very last and rather sparse section reserved for 'literary matters'. It is this shift, that Foucault has commented upon as pushing back 'all the language deposited upon things by time [. . .] into the very last category, like a sort of supplement in which discourse is allowed to recount itself and record discoveries, traditions, beliefs, and poetical figures'.[38]

But there is a further peculiarity about Linnaeus' *Methodus*. While its predecessors were either schemes presented in a preface as organising the ensuing main text (as in Gesner's *Historia animalium* or Ray's *Historia plantarum*) or just implicit schemes that can be seen to actually underlie a text itself (as in Aristotle or Aldrovandi), Linnaeus proposed his scheme independent of a natural history text and as applicable to *any* 'natural subject', i.e. universally applicable to whatever stone, plant or animal might raise the interest of a naturalist. Linnaeus' *Methodus* was designed as an abstract scheme in which each and any possible proposition about stones, plants, or animals was supposed to find its definite place, even such propositions which were wrong but nevertheless had been made, as 'idle dreams of authors' or 'vain superstitions'.[39] The *Methodus* was a tool for scanning, organising and correlating all possible contents

[36] Linnaeus, *Vitae* 145.

[37] A.J. Cain, "The 'Methodus'" 237–238.

[38] Foucault, *The Order of Things* 130. Cfr. Hoppe B., "Der Ursprung der Diagnosen in der botanischen und zoologischen Systematik", *Sudhoffs Archiv* 62 (1978) 105–130, and Jacobs M., "Revolutions in Plant Description", in Arends J.C. (ed.), *Liber Gratulatorius in Honorem H.C.D. De Wit* (Wageningen 1980) 155–181.

[39] Linnaeus, *Methodus*, par. 12 and 37.

CAROLI LINNÆI, *SVECI*,
METHODUS

Juxta quam Phyſiologus accurate & feliciter concinnare poteſt Hiſtoriam cujuſcunque Naturalis Subjecti, ſequentibus hiſce Paragraphis comprehenſa.

I. NOMINA.

1. *Nomen Selectum*, genericum & ſpecificum Authoris cujuſdam, ſi quod tale, vel proprium.
2. *Synonyma* Syſtematicorum primariorum omnia.
3. . . . Authorum, ſi poſſit, omnium Veterum & Recentiorum.
4. . . . Nomen vernaculum, latino etiam idiomate tranſlatum.
5. . . . Gentium variarum nomina: Græca præcipue.
6. *Etymologia* Nominum genericorum omnium (1-5).

II. THEORIA.

7. *Claſſes* & *Ordines* ſecundum Syſtemata ſelecta omnia.
8. *Genera* ad quæ, â variis & diverſis Syſtematicis (7) relatum fuit Subjectum propoſitum.

III. GENUS.

9. *Character Naturalis*, omnes notas characteriſticas poſſibiles exhibens.
10. . . . *Eſſentialis* notam generi maxime propriam tradens.
11. . . . *Artificialis*, genera in Syſtematibus (7) conjuncta diſtinguens.
12. *Hallucinationes* Authorum circa genus (8) ex dictis (9).
13. *Genus Naturale* demonſtrabit. (9)
14. *Nomen Generis* (13) ſelectum (11) confirmabit, & cur alia rejiciat, indicet.

IV. SPECIES.

15. *Deſcriptio* perfectiſſima Subjecti tradatur, ſecundum omnes ejus partes externas.
16. *Species* generis propoſiti (13) omnes inventas recenſeat.
17. *Differentias* omnes inter ſpeciem propoſitam (1) & notas (16) exhibeat (15).
18. . . . primarias inde retineat, reliquas rejiciat.
19. . . . ſpecificam Subjecti ſui componat, & rationem facti quoad omne vocabulum (1) reddat.
20. *Variationes* ſpeciei propoſitæ omnes apud Authores datas proponat.
21. . . . has ſub naturali ſpecie redigat cum ratione facti (15).

V. ATTRIBUTA.

22. *Tempus* productionis, incrementi, vigoris, copulæ, partus, decrementi, interitus.
23. *Locus natalis.* Regio, provincia.
24. . . . Longitudo & latitudo Loci.
25. . . . Clima, Solum.
26. *Vitæ.* Diæta, mores, affectus.
27. *Corporis* Anatomia, præſertim curioſa; & inſpectio Microſcopica.

VI. USUS

28. *Uſus œconomicus* actualis, poſſibilis, apud gentes varias.
29. . . *Diæteticus*, cum effectu, in corpore humano.
30. . . *Phyſicus*, cum agendi modo & principiis conſtitutivis.
31. . . *Chemicus* ſecundum principia conſtitutiva, igne ſeparata.
32. . . *Medicus* in quibus morbis præcipue & verè, demonſtratus ratione vel experientia.
33. . . . . Officinalis; quæ partes, præparata, compoſitiones.
34. . . . . exhibendi methodus optima, doſis, cautelæ.

VII LITERARIA

35. *Inventor* cum loco & tempore.
36. *Hiſtoricæ Traditiones* de Subjecto variæ, jucundæ & gratæ.
37. *Superſtitioſa* vana rejicienda.
38. *Poetica* egregia illuſtrantia.

LUGDUNI BATAVORUM,
Apud ANGELUM SYLVIUM. MDCCXXXVI.

Fig. 1. 'The Method of Carolus Linnaeus, Swede, in conjunction with which the Physiologist can put in order accurately and successfully the History of any Natural Subject', folio leaf published by Linnaeus (1736).

of natural history, and as such it aimed at the universal tabulation of whatever had been said, could be said, or still remained to be said about each and any of the 'subjects' of natural history.

Tabulation

Linnaeus, of course, did not attempt to actually realize the aim of universal tabulation implicit in his *Methodus*. The sheer amount of possible 'subjects' and the mass of information already compiled upon them would have prevented such an endeavour from the outset. Yet, in many of his publications we find tables which correlate particular predicates in order to detect universal regularities or 'laws (leges)' as Linnaeus called them. A good example for this strategy can be found in the dissertation *Vernatio arborum* (1753), which dealt with the time at which 'different trees begin to put forth their leaves'.[40] This dissertation contains a large table consisting of three elements: 1) a top row repeating a list of geographic locations within Sweden for three consecutive years; 2) a column to the left listing names for various species of trees; and 3) calendar dates entered in the fields resulting from the intersection of the rows columns.[41] These calendar dates represented the times at which certain species of trees had been observed to put forth leaves in various regions of Sweden. Linnaeus had obtained these dates from local correspondents after having published a questionnaire in a Swedish newspaper.[42]

On the basis of the observations thus compiled, Linnaeus argued for the existence of 'fixed laws and a certain order that trees observe in leaving; so that he, who is but moderately versed in this affair, may immediately know, when he sees one species of trees in leaf, what

[40] Linnaeus, "Vernatio Arborum", in *Caroli Linnaei Ammoenitates Academicae, seu dissertationes variae physicae, medicae, botanicae antehac seorsim editae, nunc collectae et auctae*, 7 vols. (Leiden: 1749–1769) vol. 3, 365. An English translation of *Vernatio arborum* under the title 'On the Foliation of Trees' can be found in Carl Linnaeus, *Miscellaneous tracts relating to natural history, husbandry, and physick*, ed. B. Stillingfleet (London: 1759) 133–158. About 200 dissertations were written under Linnaeus' presidency. They were based on private lectures given by Linnaeus and were collectively published under his name in the *Amoenitates Academicae*.

[41] General prescriptions for the drawing up of such tables of correlation can be found in Linnaeus, *Philosophia Botanica* 263–277.

[42] See the commentary to *Vernatio arborum* in Carl Linnaeus, *Skrifter af Carl von Linnaeus*, ed. by Kungl. Svenska Vetenskapsakademien, 5 vols. (Stockholm: 1908) vol. 4, 202.

species will be next'.[43] While the absolute dates for the beginning of foliation vary for a given kind of tree from place to place and from year to year due to variations in climate and soil, the relative dates, i.e. the order in which the different kinds of trees succeed each other in foliation, remain the same at any location and in any year. The point in all this was to replace traditional farmer's calendars, which were based on astrological reasoning, by a sure, natural sign for the optimal time to sow and cut barley (as it turns out, barley is best sown out when the birch leafs). The dissertation even made use of a statistical parameter – a 'medium', as it is called in the text – to corroborate the thesis that the time between sowing and harvest was always the same, independent of latitude.[44]

The statement of such 'fixed laws' supposed to be universally valid has an important logical implication: The 'subjects' of these statements themselves have to be universal in some sense, if the correlation referred to by the law is to count as universal at all. If the table contained in *Vernatio arborum* merely stated that this or that individual plant had been seen to put forth its leaves on this or that date at this or that location, nothing would be gained at all. Correlation with the help of tables, or, by extension, a universal scheme like the *Methodus*, would not lead anywhere in this case: Any combination of predicates would be possible with every new object coming to the attention of the naturalist, and thus also any scheme would do. Now, as we saw, the table in *Vernatio arborum* did indeed not only amass observations on particular plant individuals, but grouped these observations according to the 'species' to which the observed individuals were supposed to belong. Equally, as Arthur J. Cain has pointed out against former interpretations, the 'subject' referred to in the title of the *Methodus* is not an individual object (say, a given specimen of stone, plant, or animal), but a species of stones, plants, or animals.[45] And the species, as explained above, was defined by Linnaeus as a theoretical entity under the supposition of 'laws of generation'.

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[43] Linnaeus, *Miscellaneous tracts* 140–141.

[44] Ibid. 154–155. To my knowledge, this is one of the earliest examples for the use of statistics in the context of natural history.

[45] Cain A.J., "The 'Methodus'" 233. This is also clear from the way in which the term "subjectus" reappears in the *Methodus* under the heading '*Species*' in subheading 15: 'Let the most complete Description of the Subject be set out, according to all the external parts'; and subheading 19: 'Let him [i.e. the '*Pysiologus*' referred to in the title] put together the specific Difference of his Subject [. . .]'.

It is here, now, that we encounter a central problem related to the arrangement and processing of information in Linnaean natural history: With the supposition of species in the Linnaean sense all empirical propositions correlated by the *Methodus* become 'theory-laden' in as much as they are claimed to be universally valid for a theoretical entity reaching beyond the range of this or that particular set of individuals.[46] One can see here, why Linnaeus could believe to have transcended the tradition of natural history as dealing with particulars only. However, with the theoretical underpinning of all propositions within natural history, the subjects of these propositions, i.e. the species themselves seem to be deprived of any empirical foundation. At least, none of the various predicates assembled by the *Methodus* does, by itself, provide such a foundation: They all express something that applies universally to a given species, but does not constitute that species. The question therefore arises, which kind of empirical evidence could possibly have substantiated the Linnaean species.

One tiny and inconspicuous exception to the rule, that no heading under the *Methodus* has to do with the empirical constitution of species, can put us on the right track to answer this question: Under the final heading, *Literaria*, the *Methodus* requires to state 'the Discoverer (*Inventor*), with place and time'. The 'discovery' of a species is, if only in a very abstract and restricted sense, an event that empirically constitutes that species. To explore that sense, it is useful to examine the concrete way in which Linnaeus himself 'put in order a History of a Natural Subject'.

A New Place for History

As Cain observed, Linnaeus did not strictly adhere to the scheme he provided with the *Methodus* when he himself ventured to write about particular species.[47] This is certainly true for his taxonomic writings, such as the *Systema naturae* or *Species plantarum*, which, however, served diagnostic rather than descriptive purposes. But it is also true for those

[46] I do not, of course, speak of universality here in the usual unrestricted sense, but in the sense of 'valid for all x *as long as* x belongs to species S'. Furthermore, the propositions organised under the *Methodus* may also embrace alternatives or semi-quantitative statements like 'often' or 'mostly', yet in some sense still count as universal.

[47] Cain A.J., "The 'Methodus'" 240.

texts which Linnaeus called 'monographs', i.e. texts that gave detailed accounts of individual plant species, like *Musa cliffortiana* (1736), *Betula nana* (1743), *Peloria* (1744), *Anandria* (1745), or *Passiflora* (1745), to name just a few. The reason for this apparent inconsistency is twofold: On the one hand, of course, there was not always information corresponding to each and every of the subheadings of the *Methodus*. On the other, and more interestingly, Linnaeus' interest in particular species of plants was selective. He chose to write 'monographically' on plants posing some problem with regard to their mode of reproduction. Thus, *Betula nana* dealt with a species of birch, the dwarf-birch, which 'undergoes remarkable change (*mutationem*) according to the quality of its place of growth'.[48] *Peloria* concerned a *Linaria*-variety, which had undergone 'such a metamorphosis as has never been seen before'.[49] *Anandria* discussed a plant that 'according to name and rumour produces flowers without stamens and anthers', which was an impossibility within the framework of Linnaeus' theory of plant reproduction.[50] And *Passiflora*, finally, described a plant characterized by a 'singular structure of fructification, which especially amazed those superstitious Roman-Catholics'.[51] In short, the 'monographs' dealt with remarkable or exceptional instances of exactly those 'laws of generation' which were central to Linnaeus' taxonomic theory, in as much as they were constitutive of his species concept.

With this theoretical preoccupation of the 'monographs' in mind, one feature of their organisation, as apparent from their sub-headings, is highly interesting: While all 'monographs' roughly follow the order prescribed by the *Methodus* – first a listing of names, then a discussion of taxonomic position, then description and diagnosis of the species, then, if at all, additional information on attributes, uses and literary tradition – there appears a new section in *Betula nana* and all subsequent monographs, which carries a remarkable title, 'historia' or 'historica',

[48] Carl Linnaeus, "Betula nana", in *Caroli Linnaei Ammoenitates Academicae, seu dissertationes variae physicae, medicae, botanicae antehac aeorsim editae, nunc collectae et auctae*, 7 vols. (Leiden: 1749–1769) vol. 1, 12.

[49] Carl Linnaeus, "Peloria", in *Caroli Linnaei Ammoenitates Academicae, seu dissertationes variae physicae, medicae, botanicae antehac aeorsim editae, nunc collectae et auctae*, 7 vols. (Leiden: 1749–1769) vol. 1, 56.

[50] Carl Linnaeus, "Anandria", in *Caroli Linnaei Ammoenitates Academicae, seu dissertationes variae physicae, medicae, botanicae antehac aeorsim editae, nunc collectae et auctae*, 7 vols. (Leiden: 1749–1769) vol. 1, 248.

[51] Carl Linnaeus, "Passiflora", in *Caroli Linnaei Ammoenitates Academicae, seu dissertationes variae physicae, medicae, botanicae antehac aeorsim editae, nunc collectae et auctae*, 7 vols. (Leiden: 1749–1769) vol. 2, 212.

Table 1.

Musa 1736	**Betula nana 1743**	**Peloria 1744**	**Passiflora 1745**	**Anandria 1745**
Introductio	Introductio	Praefatio	Prooemium	**(Introduct.)**
Nomina	Nomina	Descriptio	**Historica**	Nomen
Theoretica	Species	Character	Nomina	Antidesma
Genus	Descriptio	Locus	Classes	Genus
Species	Differentia	**Historia**	Genus	Species
Attributa	Locus	Linaria	Species	Figura
Usus	**Historia**	Origo	Aliena	Appendix
Litteraria	Usus	Varietas	Locus	
	Etymologia	Diversitas	Vires	
	Figura	Classes	Usus oeconomicus	
		Genus	Poetica	
		Nomen		
		Conclusio		
		Tabula		

respectively, and shows a clear evolution over time with respect to its position within the text (see table 1).

The content of these 'historical' sections corresponds to the section on 'The Discoverer' in the earliest 'monograph' *Musa cliffortiana*, which quotes the earliest reports about *Musa* (i.e. the banana) in Theophrastos' *History of Plants* and Pliny's *Natural History*.[52] In *Betula nana* the section headed 'Historia' takes the form of a long list of short paragraphs, which always start with a year ('An. 1654 [...]. An. 1659 [...]' etc.), followed by the name of a botanist in capitals ('Loeselius [...] Frankenio [...]' etc.) and a short statement about what that botanist did with *Betula nana*. The paragraphs follow a strict chronological order, and the activities described by them are just a few in kind. These activities are:

1. first naming ('In the year 1654 Lösel in the *Catalogue of Borussian plants*, p. 10, imposed the first name of *Betula pumila, Kleinbirk*, on it');
2. first description and depiction ('In the year 1735 Linnaeus (our Praeses) in the *Laplandic Flora, pp. 266–270, tab. VI, fig. 4*, described her at length under the specific name of *Betula nana*, with synonyms, birth place, economic use etc. He was the first and also the only one who described and depicted our shrub');

[52] Linnaeus, *Musa Cliffortiana*, 180–183.

3. first finding in a certain geographic region (e.g. 'In the year 1683 TILLAND, who was the first to find her in Finnland, called her *Betula nana s. pumila, Ryeltrae Wanha Coiwu* in the *Catalogue of plants around Abo*');
4. introduction into a botanical garden ('In the year 1685 RUDBECK the Elder introduced her into the academic garden of Uppsala and called her *Betula nana Suecorum, Dwergbiörk*');
5. transmission from one garden to the other ('In the year 1740 ROYEN [...] received a small amount of seeds from those, which Prof. Browall had sent to the garden of Clifford, and cultivated them in the academic garden of Leyden').[53]

Linnaeus was explicit about the fact that the 'Historia' section fell out of the order originally conceived in the *Methodus*. A short note introducing the list of events recounted in the section in *Betula nana* announces, that 'the way of order is left aside now, so that we also may treat the history of our *Betula*, in which way, namely, it was first discovered, and how it afterwards became known to Botanists'.[54] Surprisingly, this remark refers to the function that Linnaeus had ascribed to 'history' when arguing that 'botany is nowadays not, as she was before, reckoned to be a part of history'. But if 'history [...] cared for nothing but to describe [botany's] ascent', what role could it possibly play in Linnaeus' 'new' science of botany? And how do we explain the fact that it seems to have played a role of increasing importance, at least if judged by the position the section occupied within the structure of successive monographs published by Linnaeus?

A look at the next text in the series of 'monographs', *Peloria* of 1744, can help us to resolve this issue, as in this case the section entitled 'Historia' actually tries to prove something. The 'history' told of the plant 'Peloria' may be summarised as follows: 'A certain student had first found the plant' near his home town Roslag in 1742, but had not recognised 'the value of his finding'. This student was visited the same year by the theology professor Olaus Celsius, who had a look at the specimen preserved in the student's herbarium. He 'immediately recognised' that the plant was 'remarkable' and showed the specimen to Linnaeus, who at first sight believed that 'alien flowers had been

[53] Linnaeus, "Betula nana" 13–15.
[54] Ibid. 13.

glued to' a more common plant named *Linaria*, but on closer inspection observed 'a structure not yet seen by Botanists before'. Linnaeus, 'inflamed by an incredible desire to see the living plant' sent the student to fetch a living specimen, which was then planted in the botanical garden of Uppsala. Embedded in this tale of discovery, we find the following argument:

> As the flower structure occurred to be so uncommon, he [Linnaeus] would have believed, that the plant was not indigenous to Europe, but rather had come from the Cape of Good Hope, Japan, Peru, or some other remote part of the world, if it had not been brought by the said student from Roslag, as Celsius had testified to him.[55]

The reasoning here is straightforward: The story told about the Peloria-specimens' discovery and subsequent fate in the hand of entrusted botanists testifies to its precise origin. This line of argument is taken up again in a further section of the dissertation *Peloria*, equally inserted out of the order of the *Methodus* and conspicuously entitled 'Origin (*origo*)'. This section tries to prove 'that Peloria was produced by and originated from Linaria', and claims this to be 'a greater miracle than if a pear tree produced daffodil flowers, a thistle figs, or a hawthorn grapes'.[56] The first argument adduced to substantiate this claim against all received botanical knowledge ties back (as is evident from the use of the past tense) to the section 'Historia' in the following words:

> Peloria grows among Linarias. Where Peloria was found, there Linaria abounds everywhere among the gravel, though Peloria occurred in smaller amounts.[57]

Thus the function of the 'Historia' section can be identified as tracing back the origin of a specimen through instances of genealogical relationships, that is, relationships that were constitutive of species according to Linnaeus' species concept. Such instances could consist of observations in the field, were spatial proximity was used as an indicator of common decent. But more decisive instances were produced by transferring

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[55] Linnaeus, "Peloria" 60. On the complex details of the *Peloria*-incident and the impact it had on Linnaeus' intellectual development see Larson J.L., *Reason and Experience. The Representation of Natural Order in the Work of Carl Linnaeus* (Berkeley: 1971) 90–103.

[56] Linnaeus, "Peloria" 62.

[57] Ibid.

specimens from wild population onto the beds of the botanical gardens, or by transferring specimens from one garden to the other.[58]

Now, this is precisely the role the 'Historia' section plays in the dissertation *Betula nana*: In a section entitled 'place (*locus*)', Linnaeus observes 'how wonderful it is, what amount of change our [plant] undergoes due to the kind and quality of its place of birth; growing in the mountains it hardly reaches the height of one foot [...] grown in gardens [...] it grows up to a kind of small tree'.[59] The section headed 'differences (*differentia*)', on the other hand, states that the leaves of *Betula nana* 'always' show the same, distinctive form.[60] Both the variability of the habitus and the constancy of leaf form, however, can be directly observed not in wild plant specimens but only in instances where plants are transferred and reproduced from one place to the other, be it from the wild into a garden or from garden to garden. The evidence for variability and constancy, that is, is provided by exactly those kinds of instances Linnaeus systematically compiled in the section '*Historia*'. And indeed, the section headed 'place' makes abundant references to the literature cited in the '*Historia*' section, to argue for the variability of habitus in *Betula*.

The instances of transplantations collected in the '*Historia*' section formed the raw material for a comparative procedure to which Linnaeus referred as 'collation (*collatio*)' and which was operative on all levels of his taxonomic enterprise. In general terms, it can be described as follows: Starting from a single exemplar of a kind, other exemplars judged to belong to the same kind are adduced and compared with the first. All characters observed to remain 'constant' throughout the set of exemplars are retained in the definition of the kind in question – be it a species, a genus, or a 'natural order' – while all 'dissenting' characters are excluded from it. Collation is clearly an open process; new material may always require revision of previous definitions, or 'natural characters' as Linnaeus called them. As Linnaeus phrased it in the *Philosophia botanica*: 'No definition is infallible until it has been rectified in accordance with all its own species. The most accomplished

[58] Initially, Linnaeus was not successful in reproducing *Peloria* in his garden at Uppsala. It is likely for this reason that his writings on plant reproduction did not refer to *Peloria* anymore until 1762, when reproduction in the garden had finally been successful. See Müller-Wille S., "'Varietäten auf ihre Arten zurückführen'. Zu Carl von Linnaeuss Stellung in der Vorgeschichte der Genetik", *Theory in Biosciences* 117 (1998) 346–376.

[59] Linnaeus, "Betula nana" 12.

[60] Ibid. 10–11.

botanist, and he alone, achieves the best natural definition; for it will be made by the agreement of the greatest number of species; for every species excludes some superfluous character'.[61]

It is thus possible to see how Linnaeus could believe to have overcome traditional natural history with his 'total reform' of botany, while at the same maintaining that traditional natural history remained pertinent to botany's 'ascent'. Earlier scientific activities, which had produced the mass of empirical statements digested in 'monographs' or tables of correlation, had also constituted the network of specimen collection and exchange, which instantiated the 'laws of generation' informing Linnaeus' theoretical species concept. The history of botany thus appeared to Linnaeus under two aspects: On the one hand, as a dead past that had resulted in a mere accumulation of materials to be processed by his 'new' science of botany; on the other, as a living tradition in itself constitutive of the formation of that very same science. It is history in the latter sense of a prolonged series of reproductive, distributive, and circulatory events that intrudes into the old order of natural history as presented by the *Methodus*. And it is for this reason that the decisive catchwords of nineteenth-century historicism already flash up in 1756, under the heading of 'Theoria', in the tenth edition of Linnaeus' *Systema naturae*:

> CRITIQUE. Ethymology of *generic* and *specific* names.
> Discoverer *with* time.
> Historical, critical, antique knowledge.[62]

Conclusion

Collatio is a term that Bacon also used occasionally when describing his inductive method. A particularly revealing instance of the use of this term can be found in the *Novum organum*, in the aphorism discussing 'summoning' or 'evoking instances', i.e. instances which 'make manifest things not directly perceptible by means of others which are'. One of the examples Bacon discusses here is the question of the 'quantity of

[61] Linnaeus, *Philosophia botanica* 144, par. 193. See Müller-Wille S., "Collection and Collation Baconian Science", for a more detailed analysis.

[62] Linnaeus, *Systema naturae per Regna tria naturae in classes, ordines, genera, species cum characteribus, differentiis, synonymis, locis*, tenth edition, 3 vols. (Stockholm: 1758–1759) vol. 2, 828.

matter in this or that body'. While weight is accessible to the senses, 'quantum of matter' is not. The latter may, however, be 'summoned' to the senses and 'reduced to calculation [. . .] by comparison (*facta collatione*)'. As Bacon explains:

> I have drawn up a very accurate Table on this subject; in which I have noted down the weights and volumes of all the metals, the principal stones, woods, liquors, oils, and many other bodies as well natural as artificial; a thing of great use in many ways, as well for light of information as for direction in practice.[63]

Bacon was not, as is well known, a naïve empiricist. His theory of induction was a complex one, essentially consisting, as Michel Malherbe has argued, of three steps: namely, the tabulation of observations, the recording of 'presences' and 'absences' in the process, and subsequent abstraction.[64] The importance of the first two steps has been systematically underrated by philosophers of science. There are many ways to tabulate observations and to analyse the resulting tables. Bacon owed the term '*collatio*' to his profession: 'collation', in the legal context, designated the systematic, word-by-word comparison of an original text with its copy in order to detect deviations.[65] Likewise, Linnaeus' science can be seen to rely on an almost excessive use of technologies of inscription, tabulation, and comparison. The concrete solutions he found might look very different from what Bacon himself envisioned – but they were, arguably, Baconian in spirit.

The Baconian legacy, then, must not be understood as the legacy of a particular scientific methodology. Induction is a two-tiered process. It does not only put to test our presumptions about nature by moving from particulars to general laws. It also puts to test the various ways in which one may proceed by induction. It puts to test technologies of induction, one might say, and this is the source of the close relationship between modern science and technology. Induction is an open process both with respect to the universal statements it produces and with respect to the success of the methods it employs to produce such statements. Many of the technologies of organising written information put into place by seventeenth- and eighteenth-century naturalists

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[63] Bacon, *Works* vol. 4, 197–198. For the Latin version see ibid. vol. 1, 312.

[64] Malherbe M., "Bacon's method" 86–95.

[65] Oxford English Dictionary, on-line edition, s.v. 'collation'; Zedler J., *Großes vollständiges Universallexikon aller Wissenschaften und Künste* (Halle and Leipzig: 1732–1750), s.v. 'collationieren'.

may seem trivial today. But they had to be invented, nevertheless. As Wolfgang Krohn has argued, Bacon never intended to present a formalized procedure of induction, and it is highly questionable that he was ever read that way in the seventeenth and eighteenth century.[66] Or as Michel Malherbe puts it: 'In general, [Bacon's] method is not to be understood as an imperative: it is an indication, a direction, something like a compass [. . .]. It is a way through or the effort toward the next step of knowledge.' Bacon, that is, did not define a program, but a problem: the problem of induction.

[66] Krohn W., *Francis Bacon* (Munich: 1987) 150–156; cf. Steinle F., "The Amalgamation of a Concept: Laws of nature in the New Sciences", in ed. Weinert, F., *Laws of Nature: Essays on the Philosophical, Scientific and Historical Dimensions* (Berlin: 1995) 329–334.

RESCUE ATTEMPTS: SCIENTIFIC IMAGES AND THE MYSTERIES OF POWER IN THE ERA OF LOUIS XIV

Pablo Schneider

The château of Versailles became a place of great importance after 1668. At first only a hunting lodge, King Louis XIV decided to transform it into the primary residence of the monarch. This alteration influenced the architecture and the environment of Versailles as well as its mediation in pictures and words. This essay will focus on one detail of Versailles – the fountain called the *Parterre d'Eau* – and reconstruct some structural aspects of its interpretation like the impact of limited space and the attempt to give plastic form to a scientific world view.

For the French government, the concept of sovereignty, based on the works of Jean Bodin, constituted an important contrast to a scientific way of describing and analysing nature and the cosmos. This political concept was embodied by the monarch and his personal symbol – Apollo – attaining an acceptance that transcended the value of a picture.[1] For this the sovereign was supposed to be presented as the source of all, as the *first cause*, part of a unique composition constructed according to a special ground plan with sculptures of the four elements, the temperaments, the times of day, the seasons, the continents and poems. This design was supplemented with a parnassus, a globe, personifications of the sun and the moon as well as the different ages of human beings. A great variety of themes comprise the *Parterre d'Eau* at Versailles. This composition was supposed to counter a scientific way of analysing which might include the danger, felt by those in the circle around Louis XIV, of discovering the mysteries of power and sovereignty.[2]

One example should suffice to characterise the ambiguous situation of the sciences and political authority in the seventeenth century. In 1673, the *Journal des Sçavans* reported the discovery of an unknown creature and this incident can be interpreted as a symbol of the shifting

[1] Burke P., *Ludwig XIV. Die Inszenierung des Sonnenkönigs* (Berlin: 1993) 113.
[2] Marin L., *Das Porträt des Königs* (Berlin: 2005).

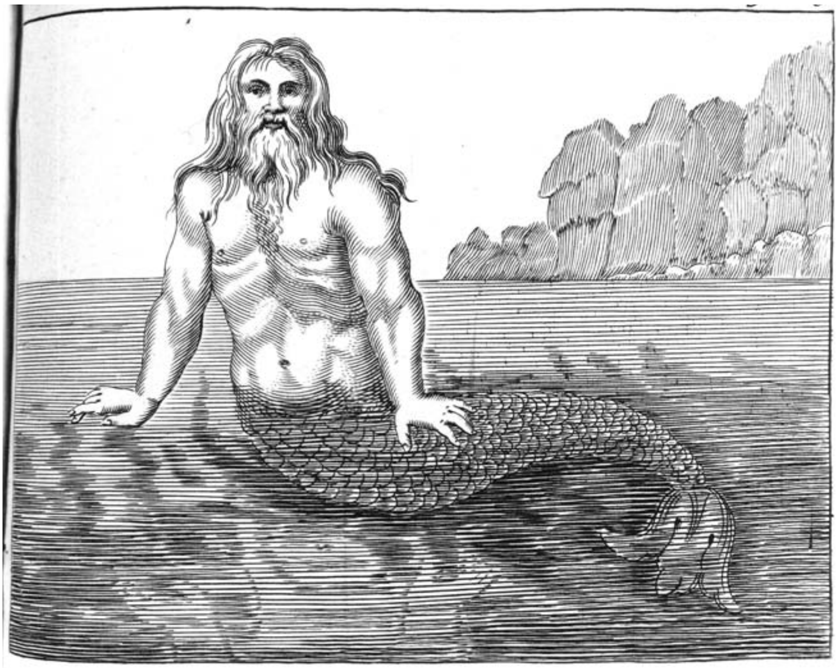

Fig. 1. *"Fishman", Journal des Sçavans*, 1673, woodcut (Staatsbibliothek zu Berlin, Ac 2810R).

character of the natural sciences.[3] The picture accompanying the article shows a friendly looking, bearded man who has a fish's tail where his legs should be.[4] But the modern observer cannot appreciate this scientific image without its iconographic and, more importantly, its iconological tradition. This creature was by no means unknown in the fields of mythology, painting, and sculpture. The words and images of the field of mythology were closely related to the various forms of representation of politics and the communication of authority. Both Neptune and other sea gods had enjoyed a long tradition in both written and figurative representation. Characters such as these played an important role in the description and interpretation of different types of political power but in an allegorical way which explained but did not analyse this power. The mysteries of power, at this time, were

[3] *Journal des Sçavans* 1673, 103–109.

[4] Concerning the term exotic chimera see Ashworth W.B., "Remarkable humans and singular beasts", in Kenseth, J. (ed.), *The age of the marvelous* (Hanover: 1991) 113–132.

understood as forces that did not lend themselves to scientific analysis. These mythological images represented certain aspects of power, for example *authority* or *morality*, and through narratives could help explain the manifestation of natural relationships and their effects. Therefore, a climactic development can be observed in the 17th century which further advanced the demystification of nature, art, and the traditional iconography of power.

Mythological topics had become part of a reality that lay beyond images. Forms of potentiality, moreover, comprised the fragile foundation of political and natural science. For example, in the book *Mundus subterraneus* by Athanasius Kircher, published in Amsterdam in 1664–1665, interpretations which integrate aspects of mythology and natural science can be found in a description of a mountain lake, which also mentions and visually documents the dragon rumoured to live there.[5] These images of a scientific domain documented the existence of things which for centuries were elements of a mythological perspective. At the same time they had become defined as objects of study for the natural sciences and no longer merely as topics for art and other allegorical forms describing the world.[6] These examples indicate the shifting nature of seeing and interpreting.[7] During the course of the 17th century, the tendency towards change became so important that it would end up transforming conceptions of the world and its determining structures. For the mythological characters offer a specific interpretation of interrelationships which affect general living conditions. With regard to the fish-man, for example, it was important whether he was perceived as a scientific or allegorical image. Readers and viewers had to analyze allegorical and narrative arrangements in order to understand the content of history paintings and the details of their picture language. For this reason, the fact of multiple assignments of referents was very important. Jupiter, for instance, represented both

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[5] Concerning the terms *miracle* and *attentiveness* see Daston L. – Park K., *Wunder und die Ordnung der Natur 1150–1750* (Frankfurt/M: 2002); Stafford B. M., *Kunstvolle Wissenschaft. Aufklärung, Unterhaltung und der Niedergang der visuellen Bildung* (Dresden: 1998).

[6] Concerning these observations see Bredekamp H., "Gazing hands and blind spots: Galileo as draftsman", in Renn J. (ed.), *Galileo in Context* (Cambridge: 2001) 153–192.

[7] In this context, the role of astronomy and its diverse modes should be discussed. Concerning the situation in France and at the royal court see Minois G., *Geschichte der Zukunft. Orakel, Prophezeiungen, Utopien, Prognosen* (Düsseldorf-Zürich: 1998) especially 444–55. Likewise Scholz Williams G., *Defining dominion. The discourse of magic and witchcraft in early modern France and Germany* (Ann Arbor: 1995) especially 121–45.

a deity and a planet. The sciences, in the early modern era, repeatedly declared that the content of mythology and history paintings – *Historia* – were also objects of interest in the field. On the other hand, the sciences began to scrutinize the unknown and invisible effects of nature and to attempt to make them manifest. On the face of it, this process was only of interest in the scientific domain, but most of the political theories of the 17th century attempted to define the sovereign as the only one, after God, who had the innate ability to explain the coherence of the world and the cosmos.

In the following and in relation to the *Parterre d'Eau* and Versailles, I will first discuss the spatial position of the sovereign in political theories. Next, I will focus on the natural sciences and their empirical analyses. These analyses will be connected to 17th-century conceptions of infinity in relation to the concept of limited space. These observations will be important for describing the monarchy's understanding of the four elements because by employing both words and images they attempt to emphasize the king's unique position. Based on these considerations, this essay will primarily focus on images and on arguments that are dealing with images.

Mysteries of Rule and the Impact on Sovereignty

In 1610, the English king, James I, pointed out the risks to the governing system from advances in science. He lamented that "in our days there is nothing unexplored", neither the "highest mysteries of Godhood" nor the "deepest mysteries belonging to kings and princes". The latter are to be seen as "gods on earth". He complains of incompetent men, "unhamperedly wading through the deepest mysteries of the monarchy and the political government by means of their written works".[8] The king is referring, here, to any kind of scientific investigation. To James I, the mystery of royal power was part of the foundation of his authority and formed the basis of his political activities. Thus, he was not to be

[8] Kantorowicz E., "Mysterien des Staates. Eine absolutistische Vorstellung und ihre Ursprünge im Spätmittelalter", in Kantorowicz E., *Götter in Uniform. Studien zur Entwicklung des abendländischen Königtums* (Stuttgart: 1998) 263–289, especially 266. In another situation James I spoke about 'his prerogative or state secret', about the 'mysterie of royal power', and also about the 'mystic adoration' which was owed to the person sitting on the God-given throne.

challenged – by scientific description and the analysis of certain issues, such as the geometrical definition of space. Why was the mystery of rule so important to a 17th-century monarch? How could a monarch be so threatened by the sciences? And, finally: were there any strategies open to the monarch to counter such threats to his power?

The similar representation of God and the king in paintings, woodcuts and sculpture was of great importance for legitimating royal actions. The monarch was depicted as directly related to God and his representative on earth. He embodied the *majesté divine*. In his book *Six Livres de la Republique*, published in 1576, the French scholar Jean Bodin set out a fundamental theory of this relationship. An expanded Latin edition was published in 1586, and an English edition followed in 1606. The *Six Books* presents a theory which commits the most important representative of the community to a political concept of sovereignty. Bodin introduces the idea that the ruler also embodies the state. Although this ideal could not ultimately be realized, the ambitious nature of the book had a powerful effect on Europeans. It sought to realize its claim with representational actions and images. Bodin described considerations relating to sovereignty as follows:

> […] what is characteristic to a sovereign is his power to regulate the law of the collective and the individuals respectively and, as to be mentioned here, not to rely on the agreement of higher people, nor of equal people, nor of lower people.[9]

The sovereign can reach such absolute power only by accepting that God and no one else is more powerful than himself. The notion of a king with such power led the scholar to conclude:

> Because there are none on earth, after God, greater than sovereign princes, whom God establishes as His lieutenants to command the rest of mankind, we must enquire carefully into their estate, that we may respect and revere their majesty in all due obedience, speak and think of them with all due honour. He, who contemns his sovereign prince, contemns God whose *image* he is.[10]

[9] Translation by the author, 'Daraus folgt, daß das Hauptmerkmal des souveränen Fürsten darin besteht, der Gesamtheit und den einzelnen das Gesetz vorschreiben zu können und zwar, so ist hinzuzufügen, ohne auf die Zustimmung eines Höheren, oder Gleichberechtigten oder gar Niedrigeren angewiesen zu sein.' Jean Bodin, *Sechs Bücher über den Staat*, vol. 1 (Munich: 1981) 292.

[10] Translation by the author, 'Da es auf Erden nach Gott nichts Größeres gibt als die souveränen Fürsten, die Gott als sein Statthalter eingesetzt hat, damit sie der übrigen Menschheit befehlen, ist es notwendig, auf ihre Stellung achtzuhaben, um

According to this observation, Christian idolatry thus becomes a legitimate element of political theory. This use of idolatry only confirmed a long tradition in England, which had begun with the use of effigies of the kings during the period of the interregnum. Furthermore, Bodin exposes the direct relationship between the sovereign and God as a fundamental aspect of ruling. This relationship made it possible to preserve the mystery of rule and its ambiguity which is perceived positively. While the direct relation to God could be described and analyzed, it eluded scientific investigation. The natural sciences and humanities were in no position to criticize this relationship. Their approaches did, however, allow reflections upon what James I called the mystery of rule to become a sort of intellectual pastime. In this context, Francis Bacon's considerations on this subject were very important. In particular, scientific images became more important, as some of their motives were transferable and able to function as *symbolic forms*.[11] It is worth remembering that scientific knowledge and discoveries were also being criticized by theology and ethics at this time. The fall of Icarus exemplifies this analytical point of view, because the story of this mythological figure was interpreted as a comment upon an empirical and scientific way of ruling nature and all of creation.

Around 1588, Hendrik Goltzius completed an etching, entitled Icarus.[12]

The copper engraving shows Icarus being hit by a sunbeam and falling into emptiness. He uses his hand to try and protect his eyes from the sunbeams. His hand is raised in an ambivalent gesture which simultaneously reveals the state of his questioning and reflecting soul. A quotation, written on a streamer in the picture refers to the punishing power of the sun:

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in Unterwürfigkeit ihre Majestät achten und verehren und über sie in Ehrerbietung denken und sprechen zu können. Wer nämlich seinen souveränen Fürsten schmäht, der schmäht Gott, dessen Ebenbild auf Erden er ist.' Ibid. 284.

[11] Ernst Cassirer describes this kind of reception thusly: 'jene Energie des Geistes [...], durch welche ein geistiger Bedeutungsgehalt an ein konkretes sinnliches Zeichen geknüpft und diesem Zeichen innerlich zugeneigt wird. [...] Eine Welt selbstgeschaffener Zeichen und Bilder tritt dem, was wir die objektive Wirklichkeit der Dinge nennen, gegenüber und behauptet sich gegen sie in selbständiger Fülle und ursprünglicher Kraft.' Cassirer E., "Der Begriff der symbolischen Form im Aufbau der Geisteswissenschaften.", *Vorträge der Bibliothek Warburg* 1921/1922 (Leipzig: 1923) 11–39, especially 14–15.

[12] On the motif of the fall of Icarus in early modern times see Wyss B., *Landschaft mit Ikarussturz. Ein Vexierbild des humanistischen Pessimismus* (Frankfurt am Main: 1990).

Fig. 2. Hendrik Goltzius, after Cornelis van Haarlem, *"Ikarus"*, around 1588, etching from: Müller J. (ed.), *Die Maske der Schönheit. Hendrik Goltzius und das Kunstideal um 1600* (Hamburg: 2002) 93.

> SCIRE, DEI MUNUS, DIVINUM EST NOSCERE VELLE/SED FAS LIMITIBUS SE TENUISSE SUIS./DUM SIBI QUISQUE SAPIT NEC IUSTI EXAMINA CERNIT,/ICARUS ICARYS NOMINA DONAT AQUIS. (Knowledge is God's gift, it is divine to aspire to it, but it is also fitting to limit oneself when doing so. For he who considers himself wise and does not heed the considerations of the just is the one who, as Icarus, gives the Icarian waters their name.[13]

Such admonitions signify a Christian interpretation of the text. Yet the fall of Icarus – dramatic on the one hand and artificial on the other – also shows the consequences of seeking knowledge. With the questioning gesture of the left hand, Goltzius presents Icarus's thoughtful dialogue with the divine tribunal. Thus, the crucified one's search for meaning: "My god, my god, why have you deserted me?" is presented in this image with its mythological and pagan content. The divine category of knowledge and the demands of the human search for meaning and understanding were connected to the notion of reaching a limit. As a result, the motif of reaching a limit and/or overcoming such a limit assumed great significance in the early modern era.

Bacon's Scientific Approach – The Columns of Hercules

Drawing on this interpretation of the picture of Icarus, the following discussion will focus on aspects of infinity, scientific progress and the interpretation of space which will be important for describing the conceptual background of the *Parterre d'Eau* at Versailles.

In 1620 Francis Bacon's *Instauratio magna* was published. Simon de Passe completed the engraving of the frontispiece, which was supposed to be a symbol of human inquisitiveness. To create the engraving, Passe used motifs which were both well-known and expressive. Initially, the two columns in the foreground referred to Hercules's columns. At the same time, however, they symbolized the edge of the known world and the *entrée* into the unknown. The latter was something to be resolved by scientific means. The two columns were familiar in the iconography of the Habsburg emperor Charles V. He had made them his emblem

[13] Quoted from Müller J. – Roettig P. – Stolzenburg A. (eds.), *Die Maske der Schönheit. Hendrik Goltzius und das Kunstideal um 1600* (Hamburg: 2002) 90.

Fig. 3. Simon de Passe, title copperplate of Francis Bacon's *"Instauratio magna"*.

by adding the words *plus ultra* to them.[14] From that point on, the motif became a universally recognized feature of official image policy. Francis Bacon may well have been aware of this. It has been suggested that he welcomed the way in which the scene was connected to ideas relating to the exercise of power and to knowledge acquisition.

The frontispiece of the *Instauratio magna* shows Doric columns placed upon pedestals. In each case, they are standing upon a narrow piece of land which reaches out into the centre of the picture. Between them, a ship can be made out attempting to pass through the strait, a task complicated by rough seas and three huge fish. Far off in the background, a second ship can be seen which is moving from the right into the center.

[14] For the motto quod vide Rosenthal E., "Plus ultra, Non plus ultra and the columnar device of Emperor Charles V", *Journal of the Warburg and Courtauld Institutes* 34 (1971) 204–228; Burke P., "Repräsentation und Re-Präsentation. Die Inszenierung des Kaisers", Soly H., *Karl V. 1500–1558 und seine Zeit* (Cologne: 2003) 393–475.

The scene takes place in front of a broad horizon which takes up the whole engraving. The inharmonious proportions of the details suggests an emblematic interpretation.[15] Moreover, a close connection between the suggestive content of the frontispiece and the theoretical aim of Francis Bacon's work, to interpret for example the potency of Nature, can also be assumed.

In connection with the monarchical exercise of power and the acquisition of scientific knowledge, the motif must also be examined critically, because the scene can be understood to contain attempts at explaining the world. The explosive nature of the motif could only be kept in check by the representation of the borders of the known world, according to the interpretative schemes of the ancient world, and the link to a visual political language with the reference to Charles V's emblem. The frontispiece of the *Instauratio magna* did, however, exert an enduring influence on the interpretive possibilities of the open, unbounded horizon.[16] The image emphasized the relationship between scientific attempts to explain the world and a new definition of boundaries as an allegorical motif for the representational language of the 16th and, even more, the 17th century. Similarly, Joachim Patenier's tableau, "The crossing to the netherworld", completed in 1521, points to the psychological dangers in a person's life with the use of an open border. From this point on, the frontispiece inspired a different interpretation of the open horizon, for it provided a clear image for scientists' claims of comprehensive understanding in the 17th century. Bacon used the open horizon motif, in his *Instauratio magna*, in particular to introduce the visual argument of crossing a border. Bacon suggested that a complete analysis of nature could be achieved by means of a description which continuously approached its subject. He did not limit his thesis to the present but also applied it to the future, thus demonstrating the forward looking nature of his interpretation.[17] For Bacon, the columns of Her-

[15] For the various interpretations, see Konersmann R., "Francis Bacon und die grosse simple Linie". Zur Vorgeschichte perspektivischer Metaphorik, Gerhardt V. – Herold N. (eds.), *Perspektiven des Perspektivismus* (Würzburg: 1992) 33–57, especially 33–34.

[16] On the horizon as a topic, see Koschorke A., *Die Geschichte des Horizonts. Grenze und Grenzüberschreitung in literarischen Landschaftsbilder* (Frankfurt am Main: 1990); Krüger P., "Auf den Standort kommt es an. Zur Rolle des Horizonts in der Perspektive der Neuzeit", in Laufhütte H. (ed.), *Künste und Natur in Diskursen der Frühen Neuzeit* (Wiesbaden: 2000) 475–495.

[17] On the imagination see Zittel C., "Truth is the daughter of time. Zum Verhältnis von Theorie der Wissenskultur, Wissensideal, Methode und Wissensordnung bei Bacon", in Detel W. – Zittel C. (eds.), *Wissensideale und Wissenskulturen in der frühen Neuzeit* (Berlin: 2003) 213–238.

Fig. 4. Joachim Patenier, *"Die Überfahrt in die Unterwelt"*, 1520–1524, oil, Madrid, Prado, from: Pons M./Barret A., *Patinir oder die Harmonie der Welt* (Cologne: 1981) 67.

cules did not signify an ultimate hindrance but had by then degraded to metaphors. His scientific method is thus all the more impressive, as Bacon pointed to a notion of the unlimited nature of science, which could be extended to include subjects concerning every detail of the world and the cosmos.[18] The open horizon therefore become the leitmotif for the demand for scientific explanation. This development was intensified by the option to cross borders. James I viewed the change in the traditional structures of power, as a result of scientific discoveries, as a threat. In *Novum organum*, published in 1620, Bacon described science as an *image of truth*, whereas Jean Bodin in 1576 had considered the sovereign to be the *image of god*. In 1620, this change was so stunningly illustrated by the Simon de Passes' frontispiece that it left an impression on the entire century.

[18] Klein J., "Plus Ultra: Bacons Vision der Welterkenntnis im Spiegel der Begründung und Universalapplikation empirischer Wissenschaft", Dürr R. (ed.), *Expansionen in der Frühen Neuzeit* (Berlin: 2005) 233–250, especially 241–242.

The Problem of Infinity and the Position of the Sovereign

Francis Bacon's works were almost immediately translated into French. Jean Baudoin, an artistic scholar with links to the royal court, was, for example, responsible for some of these translations. Bacon's essays were first published in 1620. In 1666, the *Journal des Sçavans* in Paris reviewed Bacon's *Opera omnia*. Bacon's written works were, therefore, well-known to the French, as was his goal of providing an extensive description and decryption of nature. The French were also acquainted with Bacon's broad methodical aims, as presented in *Novum organum*: 'whether I speak of natural philosophy only, or whether I mean that the other sciences, logic, ethics, and politics, should be carried on by this method.'[19]

The notion of extending the borders of knowledge with the scientific method was, however, explicitly opposed by French scholars.

In opposition to Bacon, the philosopher Blaise Pascal strongly criticized the transgression of the horizon by science, emphasizing the concept of infinity. By using a powerful metaphorical language, Pascal rejected a scientific interpretation of the visible world. In *Pensées*, a collection of Pascal's texts published after his death, the following reflections concerning the perception of God can be found: Firstly, emphasizing vision and perception, Pascal suggests observing nature in its entirety, thus enabling an abstraction from the 'low things' of his immediate surroundings. Humans should direct their attention to the eternal light that illuminates the universe. To this end, a wide circle is drawn in the description, making the earth look like a tiny spot in comparison. Starting from this comparative localization, the French philosopher concludes:

> The whole visible world is only an inconspicuous dash within the wide circle of nature. No idea is able to approximate it, we could extend our images of thought far beyond imaginable spaces and still, compared to real things, we would only end up with atoms. It is an infinite globe, whose centre is everywhere and whose periphery is nowhere. After all, it is the most noticeable trait of the almighty God that our imagination loses its footing when thinking about such things.[20]

[19] Francis Bacon, *Works*, ed. J. Spedding, Vol. 4 (London: 1860), 112.

[20] Translation by the author, 'Die ganze sichtbare Welt ist nur ein unscheinbarer Strich im weiten Kreis der Natur. Keine Idee reicht an sie heran, wir können unseren Gedankenbildern noch so sehr über die vorstellbaren Räume hinaus ausweiten, wir bringen doch nur Atome im Vergleich zu den wirklichen Dingen hervor. Es ist eine unendliche Kugel, deren Mittelpunkt überall und deren Peripherie nirgendwo ist.

Pascal describes a world in which objects, i.e. civil achievements like the microscope for example, cannot claim the divine power of creation granted by nature. Thinking about the nature of God is one reason why people, who have the ability to imagine and create, are losing their footing. Pursuing this question further, Pascal asks what it is to be a human being in an infinite space. In so doing, however, he does not initially consider infinity in terms of the cosmos, as might be expected. Instead, he studies a mite, almost as if he were working with a microscope.[21] By finding incomparably minute elements within the tiny body of the insect, he ends up questioning the use of such scientific analysis by concluding that nature: 'must be perceived mutely rather than explored pretentiously.'[22]

Following this brief digression into the world of the tiniest creatures, Pascal returns to his main theme by reconsidering the concept of infinity. He ultimately explains the reason for humanity's lack of a sense of place as a result of its relationship to God, which can be viewed as a process of approximation and the more religious aligned method of an never ending description. Having reached a provisional conclusion with this observation, he ends his reflections with a single melancholic phrase: 'The eternal silence of these infinite spaces frightens me'[23]

In his thoughts about the nature of God, Pascal relates the concept of infinity to the description of space as well as to the characterization and valuation of the scientific analysis of microcosm and macrocosm.[24]

Schließlich ist es der fühlbarste Wesenzug der Allmacht Gottes, daß unsere Phantasie bei diesem Gedanken den Boden verliert.' Blaise Pascal, *Pensées. Gedanken über die Religion und einige andere Themen* (Stuttgart: 1997) Fragment 199/72, 131.

[21] Compare the position of Pascal, whose reflections on goodness stands in opposition to a mechanistic point of view, to that of Constantijn Huygens, who wrote a poem entitled, *About the telescope*: 'Götter, möchte man sagen, werden schließlich die sterblichen sein,/Wenn sie imstande sind, sowohl fern und nah, hier und überall zu sein.' Quoted from Alpers S., *Kunst als Beschreibung. Holländische Malerei des 17. Jahrhunderts* (Cologne: [2]1998) 63, also Bredekamp H., *Antikensehnsucht und Maschinenglauben. Die Geschichte der Kunstkammer und die Zukunft der Kunstgeschichte* (Berlin: 1993) 136–137.

[22] Translation by the author, '[…] sie schweigend zu betrachten, als sie voll Anmaßung zu erforschen' Pascal, *Pensées*, 133.

[23] Translation by the author, 'Das ewige Schweigen dieser unendlichen Räume erschreckt mich.' Ibid., 141. Benevolo did not see the order of cosmos and mankind as a fundamental topic in the landscape paintings done by Nicolas Poussin in the 1640s, but the latter 'nunmehr allein gegenüber der Unendlichkeit des Raumes.' Benevolo L., *Fixierte Unendlichkeit: Die Erfindung der Perspektive in der Architektur* (Frankfurt am Main/M-New York: 1993) 37.

[24] For a continuation of this see Auerbach E., „"Über Pascals politische Theorie.", Auerbach E., *Gesammelte Aufsätze zur romanischen Philologie* (Bern-Munich: 1967) 204–221.

At the same time, he explicitly criticizes the position of the sovereign. In this connection, he continues:

> As this central location that has fallen upon us will always be far from extremes, why should one be concerned with the fact that someone else understands things a little better; even if they really are able to grasp things from a higher point of view, wouldn't they still be endlessly far away from the endpoint, and isn't the length of a human life subject to eternity in the same way, even if it continues for another ten years?[25]

The *Memoires* of the French king Louis XIV, which can be thought of as a series of instructions on how to rule, also contain some ideas concerning the relation of spatial position to knowledge. Though not particularly focused on infinity, he described a spatial relationship that will not be unimportant for the analysis of the *Parterre d'Eau*. And such view were already broadly accepted by virtue of the power relations in early modern times. In 1661 Louis XIV noted that: [...] plus la place est élévée, plus elle a d'objets qu'on ne peut ni voir ni connaître qu'en l'occupant.[26]

Thus, a person in a higher position is much more concerned with such things than other, lower people are. Louis XIV does not merely claim that the sovereign occupies a higher position but also that from this position he is capable of revealing a much broader range of knowledge.[27] Yet the description of location is noteworthy, since this description remained important in the following decades.

In 1690 Antoine Furetière published his *Dictionnaire universel* where, in an explanation of the concept of *Infinité*, he noted that,:

> We have a quite distinct concept of infinity as an abstraction which consists of that which we call infinite, of that which we will never completely be

For the evolution of the analysis of microcosm and macrocosm see Blumenberg H., *Die Lesbarkeit der Welt* (Frankfurt am Main: 1983) 68–85.

[25] Translation by the author. 'Da diese Mitte, die uns zugefallen ist, immer von den Extremen entfernt sein wird, was macht es dann schon aus, daß ein anderer die Dinge etwas besser versteht, falls er das wirklich vermag, und wenn er die Dinge von einem etwas höheren Standort aus erfaßt, ist er dann nicht immer noch unendlich weit vom Endpunkt entfernt, und ist die Dauer unseres Lebens nicht der Ewigkeit gleichermaßen unterlegen, ob es auch zehn Jahre länger währt.' Pascal, *Pensées*, 137.

[26] Ed. Longnon J., *Mémoires de Louis XIV.* (Paris: 1978) 31.

[27] Hinrichs C., "Zur Selbstauffassung Ludwigs XIV in seinen Mémoires", *Formen der Selbstdarstellung. Analekten zu einer Geschichte des literarischen Selbstportraits. Festgabe für Fritz Neubert* (Berlin: 1956) 145–160.

> able to understand [...] If one could keep moving forward in an endless space for all of eternity, one would never see the end coming.[28]

The entry does not refer to any political interpretation. In fact, theological and moral perspectives were actually of greater interest. Thus, he concludes: The infinity of God is incomprehensible. Absolute infinity belongs only to God.[29]

This observation about and meditation on God stood in opposition to the broad scientific claims of Francis Bacon which had been presented so effectively on the frontispiece of the *Instauratio magna*.

Pascal rejected the investigation of infinity from a theological perspective and, in doing so, pointed out a more fundamental set of problems. The exclusive position of the sovereign came about due to his direct connection to God, conveyed in a highly effective way through a remarkable interpretation of infinity and limits by the French government. In connection to this, it is worth mentioning a project that was planned by the French monarchy late in the 17th century which sought to relate the concept of spatial limitation to the concept of the sovereign. In this way, representations of the French king were connected with the image of a delimited area that can be interpreted as a powerful reflection upon his political sovereignty, thereby generating the background for the project of the *Parterre d'Eau*.

Rescue Attempts – Versailles, the Four Elements and the Motif of Limited Space

In 1668, Pierre Patel completed a picture showing a view of the castle and gardens of Versailles.

The detailed execution of the canvas, depicting the garden before it was extensively rebuilt, is impressive. The forecourt, the castle, and the garden all emerge from a high visual focus point. Following the centreline, the line of sight moves into the distance. The valley is framed

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[28] Translation by the author. 'Wir haben eine ziemlich klare Idee von der Unendlichkeit als einer Abstraktion, die nur daraus besteht, das, was wir unendlich nennen, als das, was wir nie werden ausschöpfen können, zu verstehen. Würde man während der ganzen Ewigkeit in einem unendlichen Raum immer geradeaus gehen, würde man das Ende nie kommen sehen.' Furetière A., *Dictionnaire universel* (Den Haag: 1727, reprint Hildesheim: 1972) keyword *Infinité*.

[29] Translation by the author, "Die Unendlichkeit Gottes ist unbegreiflich. Die absolute Unendlichkeit gehört Gott allein." Ibid.

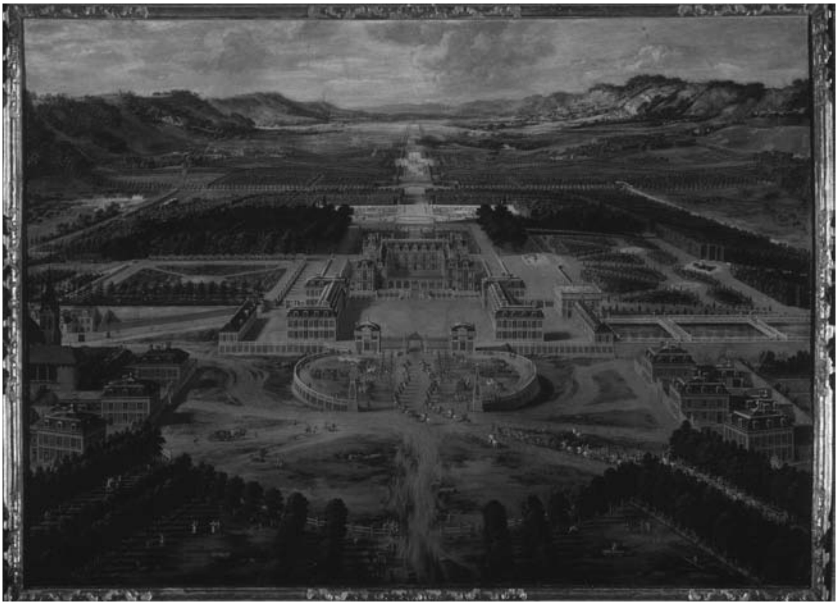

Fig. 5. Pierre Patel, *"View of the castle and garden of Versailles"*, 1668, oil-painting, Versailles (Bildarchiv Preußischer Kulturbesitz 2006).

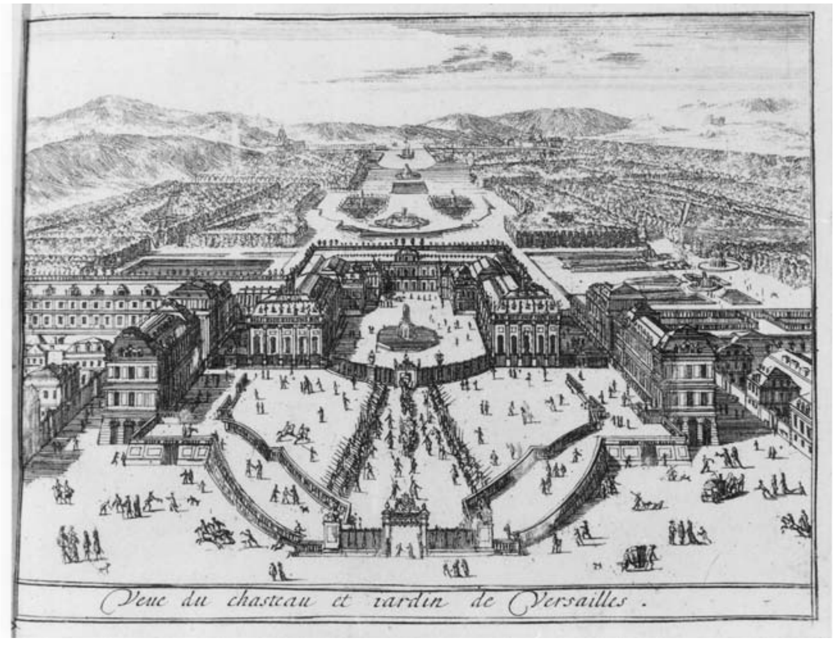

Fig. 6. Anonymous, *"View of the castle and garden of Versailles"*, 1685, etching (Herzog August Bibliothek Wolfenbüttel, Gk 494).

by ridges to the left and the right and is closed off by the mountains in the far distance. The buildings of Versailles are presented in clear opposition to the natural elements of the surrounding landscape.[30] The centreline can be easily followed – the observer's line of sight is focussed onto it. There is, however, no visual indication that the mountains can be scaled and crossed, which is quite remarkable, given the fact that the political idea of an endlessly powerful sovereign had been valued as a symbolic form of absolutism and was being represented in both paintings and architecture.[31] It is an open question whether Patel depicted the view of the castle and garden of Versailles simply to describe the natural surroundings accurately. The picture is actually one of the few that truly represents the garden as it really was. The palace grounds are indeed enclosed by a wide valley that is clearly visible from the north and south. The natural border on the west side, on the other hand, tends to vanish in mist and remains nebulous. Patel depicts the environment of Versailles precisely without adding the striking motif of infinity, which would have been seen as a reference to both the sovereign and to absolutism. Nevertheless, the 1668 canvas avoids such artificial arrangements.

The *Description du chasteau de Versailles*, published anonymously in 1685, includes an etching depicting the court of honour's façade and a view guided by the centreline.

It should also be considered a further example of the motif or visual convention of presenting Versailles as located in a limited area. The boscages are depicted accurately and, in the background, a boat can be seen sailing through a large canal. Beyond the boat, the enormous mountain range again rises up, enclosing the area. The grounds appear to be almost constrained by their natural borders. The park section itself is structured by means of centrelines which do not attempt to cross the borders of the mountains. Although it would not have been unusual to separate the mode of depiction from the actual geographical facts,

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[30] For the topic of borderlines from an art historian's point of view see Kemp W., "Text/Kontext – Grenze/Austausch. Zugleich ein Versuch über Nancy zur Zeit Stanislas Leszcynskis", in Gaehtgens Th. (ed.), *Künstlerischer Austausch. Akten des XXVIII. Internationalen Kongresses für Kunstgeschichte* (Berlin: 1993) 653–664.

[31] A different analysis of Versailles assumed the topic of infinity in connection with the castle and the park. This resulted in an interpretation of absolutism as a boundless political system. For example, see Alpatow M.W., "Versailles", *Studien zur Geschichte der westeuropäischen Kunst* (Cologne: [2]1996) 250–275 (first edition 1935), 253–266 and Weiss A.S., *Mirrors of infinity. The French formal garden and the 17th century metaphysics* (Princeton: 1995) 58–63.

this representation of Versailles neither extends beyond the horizon nor seeks to include the concept of infinity in its visual language. But the *Description* is only one example of a large number of images showing Versailles with mountains as a clear symbol of a natural border.

While Pascal's conclusions had already provided some indications of the interpretation of horizon and infinity, this concept was further elaborated in the representation of the French king, Louis XIV. In his *Six Books*, Jean Bodin clearly defined the main characteristics of the sovereign: 'The noblest distinguishing feature between a king and tyrant is that the king yields to the limits of nature [...]'[32] Bodin defines the concept of a limit or border as a distinguishing political feature. The sovereign accepts the limit, thus revealing his royal identity. In contrast, the all-powerful ruler does the opposite, disregarding all limits and thus acting erratically. The well-known phrase of the Habsburg emperor Charles V, *plus ultra*, must be considered as a counter image to royal representation in the era of Louis XIV, since it indicates a firm crossing of borders.[33]

Some initial indications regarding the virtue of self-restriction were provided by the mountain sections in the various depictions of Versailles. The presence of the mountains indicated that the place symbolized a state project that did not extend beyond the horizon. This notion is exemplified by one of the most important representational projects of the first period of Louis XIV's reign. Between 1666 and 1669 and 1673 respectively, the *Quatres Saisons* and *Quatres Éléments* tapestries as an part of the Tapisseries du Roy were completed, which also established a remarkable connection to this phenomenon.[34]

Combining allegorical elements with emblematic ones, the *Tapisseries du Roy* represented an innovation for the French people. The central theme, which incorporated iconography, Latin inscriptions and devises,[35] was developed by the *Petit Académie*. It describes the relationship between

[32] Translation by the author. 'Das vornehmste Unterscheidungsmerkmal des Königs von Tyrannen besteht nun aber darin, daß der König sich den Grenzen der Natur beugt [...]' Bodin, *Sechs Bücher über den Staat*, vol. 1, 353.

[33] For the topic boderline also Polleroß F., "Sonnenkönig und österreichische Sonne. Kunst und Wissenschaft als Fortsetzung des Krieges mit anderen Mitteln", *Wiener Jahrbuch für Kunstgeschichte* 40 (1987) 239–256; Schumann J., *Die andere Sonne. Kaiserbild und Medienstrategien im Zeitalter Leopolds I.* (Berlin: 2003).

[34] Zum Medium der Bildteppiche Brassat W., *Tapisserien und Politik. Funktionen, Kontexte und Rezeption eines repräsentativen Mediums* (Berlin: 1992).

[35] On this Fumaroli, M., "Un art royal", Grivel, M. – Fumaroli, M. (eds.), *Devises pour les tapisseries du Roi* (Paris: 1988) 7–17.

microcosm and macrocosm[36] by pointing out the theory of the four elements, earth, fire, water, and air, and integrating them into the representation of the monarch. The central message of *Quatres Éléments* was developed to present Louis XIV as a ruler who, by governing virtuously, had brought about a new, peaceful epoch in France. The distribution of the series was, from 1665 onwards, supplemented with a whole range of different and often very ornate publications. In the book the tapestries were presented in full size, and complemented with details taken from them, which were generally framed by cartouches and positioned at the edge of the paper. André Félibien was then assigned to add written explanations to the images.[37] The publications assured proper reception by the target audience, European *court society*, in accordance with the Crown's wishes, and facilitated the distribution of the images and their ideas independently of the expensive single tapestries. For example Johann Ulrich Krauß released an extensive French-German edition in Augsburg in 1687.

Each of the tapestries in the *Quatres Éléments* series presents a pair of gods embodying earth, fire, water, and air. These images are then enclosed in an elaborate frame. Water was illustrated with Neptune and Thetis. A cartouche has POUR LA PIETRÉ on the frame.

The picture shows a view of an endless, calm sea. Two boats are visible, although only one of them appears in schematic form in the left background. The Latin title, NUSQUAM DATA LITTORA TRANSIT, asserts that the ocean never will overrun its natural and God-given borders.

Félibiens claims that the limits of the ocean are set by God and therefore cannot be transcended, and the reign of the French king must be considered in a similar fashion.

> IX. POVR LA PIETRÉ, DANS LA PIECE DE L'ELEMENT DE L'EAV. Une Mer, avec ce Mot, NUSQUAM DATA LITTORA TRANSIT, quelque vaste que soit l'Ocean, il ne passe jamais les limites que le doigt de Dieu luy a marquées sur son riuage: Ainfi, quelque grande que foit la Puissance de Sa Majesté, elle ne va jamais au dela des bornes de

[36] For an philosophical and historical interpretation of the four elements see Böhme G. – Böhme H., *Feuer, Wasser, Erde, Luft. Eine Kulturgeschichte der Elemente* (München: 1996); Peil D., "Das Schema der vier Elemente in der politischen Metaphorik", Rigotti F. – Schiere P. (eds.), *Aria, terra, acqua, fuoco: i quattro elementi e le loro metafore* (Bologna-Berlin: 1996), 213–237.

[37] Concerning Félibien more specifically Germer S., *Kunst – Macht – Diskurs. Die intellektuelle Karriere des André Félibien im Frankreich Louis XIV.* (Munich: 1997).

IX.

POVR LA PIETRÉ,

DANS LA PIECE DE L'ELEMENT DE L'EAV.

Vne Mer, auec ce Mot, NVSQVAM DATA LITTORA TRANSIT. quelque vaſte que ſoit l'Ocean, il ne paſſe jamais les limites que le doigt de Dieu luy a marquées ſur ſon riuage: Ainſi, quelque grande que ſoit la Puiſſance de Sa Majeſté, elle ne va jamais au dela des bornes de la Iuſtice, qui ſont les ſeules que Dieu luy a données, & que ſa Pieté luy rend inuiolables.

Auf die Gottſeeligkeit.

In das Stuck vom Element deß Waſſers.

Eine See mit diſen Worten: Sie überſchreitet hie / deß Ufers Schrancken nie.
Anzuzeigen/ wie groß und weit auch der Ocean, ſo überlaufft er doch niemal die Schrancken/ welche GOttes Finger ihm vorgeſchriben / alſo wie groß und mächtig auch ſeiner Majeſtät Macht ſeyn mag/ ſo übergeht ſie doch niemal die Schrancken der Gerechtigkeit/ welche die jenigen ſeyn/ ſo GOTT Ihro Majeſtät vor geſchriben.

Bien qu'en tout l'Vniuers mon Empire s'étende,
Que le plus ferme Cœur ma colere apprehende
Et tremble au moindre de mes coups,
Je ne m'étens jamais au dela des limites,
Qu'à mon vaſte pouuoir l'Eternel a preſcrites,
Meſme au plus fort de mon courroux.

Ob meine Herrſchafft zwar ſich durch die Welt erſtreckt/
So/ daß mein Zorn das Hertz der Tapfferſten erſchröckt/
Und ieder zittert auf mein gar geringes Wancken/
So überſchreit ich doch niemalen meine Schrancken/
Die mir und meiner Macht geſchriben hat der Höhſt/
Auch nicht/ wann ſich mein Wuth aufs grauſamſt hören läßt.

Fig. 7. Cartouche *Pour la Pietré*, 1687 (Herzog August Bibliothek Wolfenbüttel, P S 22 b Helmst.).

> la Iustice, qui sont les feules que Dieu luy a données, & que sa Pieté luy rend iniolables.[38]

For as great as his power may be, the king would never act unjustly, and God himself has shown the king the limits of justice. Félibien explains this point as follows:

> Bien qu'en tout l'Univers mon Empire s'ètende, Que le plus ferme Cœur ma colere apprehende. Et tremble au moindre d'e mes coups, Je ne m'étens jamais au dela des limites, Qu'à mon vaste pouvoir l'Eternel a prescrites, Mesme au plus fort de mon courroux.[39]

In this way, Louis XIV was presented as a genuine sovereign by virtue of the fact that, among other things, he did not presume to possess infinite power. The king's exclusive and immediate connection to God became a form of self-imposed restriction. This construct enabled God's superior position to be confirmed, while Louis XIV was presented as the virtuous, Christian sovereign. It was the very restriction on his powers that characterized him as the true *rex christianissimus*.[40]

A comparison of the two images depicting the sea and the open horizon and diverse interpretations of these images represented a climactic development which included both scientific description and explanation as well as the representation of power. Ultimately though, it was the overwhelming desire to interpret the world and the cosmos that was being debated. The fact that the French monarchy sought to win this conflict without attracting undue attention to itself is demonstrated by the *Parterre d'Eau* in Versailles.[41]

As can be seen in a drawing by Lievin Cruyl from 1685, the *Parterre d'Eau* was to be built in front of the castle's garden façade.

The basin and the façade were to be artificially combined to create a unique arrangement. The ground plan shows five basins which integrated both circular and square geometrical forms.

Another view of the *Parterre d'Eau*, produced by Charles Le Brun's workshop, presents the view from the castle.

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[38] Krauß J.U., *Tapisseries du Roy, ou sont representez les quatre Elemens et les quatres Saisons. Avec les devises qui les accompagnet et leur explication* (Augsburg: 1687) Tafel IX.

[39] Ibid.

[40] For the topic of the *rex christianissimus* in the times of Louis XIV see Erben D., *Paris und Rom. Die staatlich gelenkten Kunstbeziehungen unter Ludwig XIV.* (Berlin: 2004) 301–303.

[41] See Schneider P., "Die komposite Welt des *Parterre d'Eau* der Gartenanlage von Versailles 1672–1683. Charles Le Brun im Spannungsfeld von Kunst und Wissenschaft", *Die Gartenkunst* 2 (2000) 257–274.

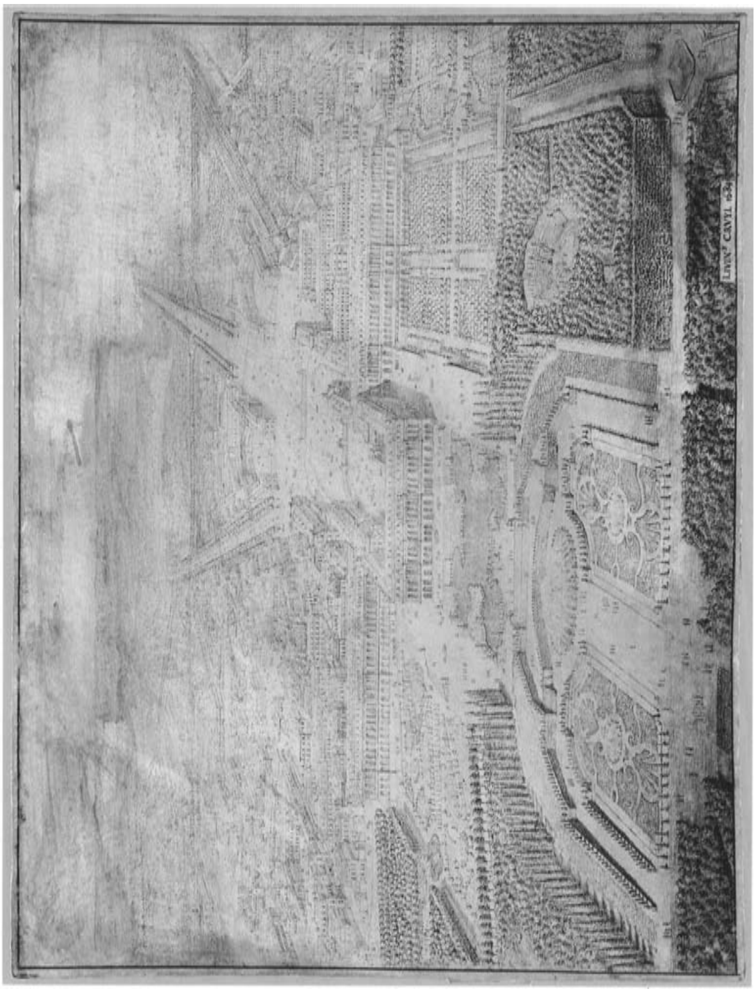

Fig. 8. Lievin Cruyl, *"View of the Parterre d'Eau"*, 1685, drawing (Paris, Musée du Louvre, Département des Arts graphiques).

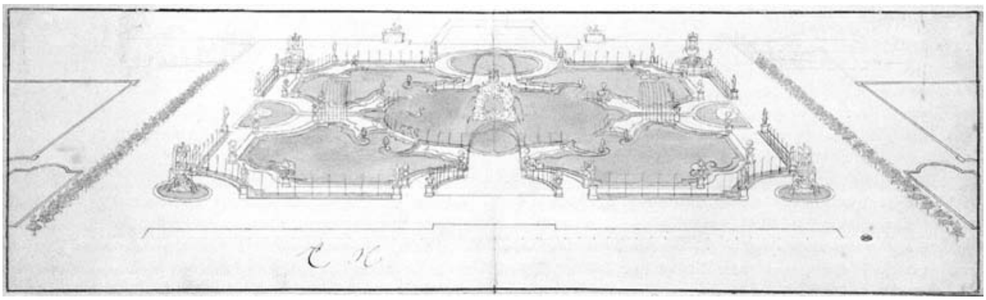

Fig. 9. Workshop of Charles Le Brun, *"View of the Parterre d'Eau"*, drawing (Paris, Musée du Louvre, Département des Arts graphiques).

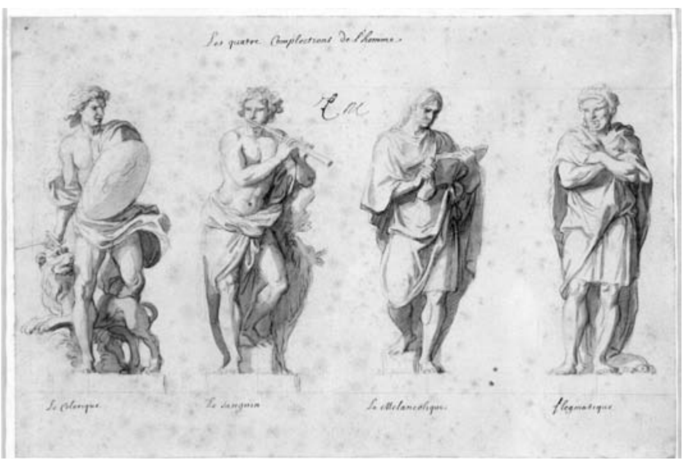

Fig. 10. Workshop of Charles Le Brun, *"The four temperaments"* (Château de Versailles et de Trianon).

As the view looks out from the 1st floor, the entire grounds are visible. A sculpture of Mount Parnassus was placed in the middle of the grounds, allowing it to be clearly seen. On its peak sits Apollo, crowned with a laurel wreath. The fountains on the mountain lead the spectator to look outwards, revealing an elaborate sculptural arrangement. Four smaller basins were considered a separate ensemble, with twenty sculptures. They contained the four elements, temperaments, seasons, times of day, and poetic arts arranged together.

The sculptures which were planned for the corners were based on Ovid's *Metamorphoses* and were supposed to be regarded as yet another representation of the four elements.[42] Looking at the group, which contains Pluto and Proserpine, allows the various levels of arrangement presented by the *Parterre d'Eau* and the garden façade to be discussed in a more precise way. The mythological figures were supposed to represent the four elements again – but differently this time.

François Girardon's sculpture shows Proserpine being abducted by Pluto. The depiction closely follows the narrative in the fifth book of the *Metamorphoses* and combines various parts of the text. At the start of the narrative, Ovid presents a peaceful atmosphere by describing Proserpine picking some flowers in a grove. Pluto sees her, is overcome with desire and thereupon abducts the daughter of Zeus and Demeter. It is at this point that the sculpture of Girardon takes up the story. Proserpine, trying to resist his advances, struggles against him with her arms spread out. Her dress falls off her body and is only laying on her left thigh. Pluto pulls her tight to him while stepping forward to complete his abduction. In doing so, he steps over Cyan, sitting on the ground.

Girardon's sculpture group combines several parts of the narration into a single scene. The energetic battle, the grabbing and resisting, are shown with struggling bodies, thus revealing the dramatic agitation of the scene. The sculptural image language does not deny the brutality of the incident. It is supposed to recount a mythological narrative and, at the same time, to address a wider range of topics, that of the four elements. The abduction scene with Pluto and Proserpine was contextualized in the sculptural groups concerning the element of fire. Since in the 17th century this interpretation could not be connected to

[42] See also *Boreas and Orithyia*, *Pluto and Proserpine*, *Saturn and Cybele* and *Neptun and Coronis*.

Fig. 11. François Girardon, *"Pluto and Proserpine"*, sculpture (Château de Versailles et de Trianon).

a particular iconography, reliefs were placed upon the plinths to show the elements in terms of their natural appearance.[43] Such a method of image explanation thus ensured a clear interpretation which meant that any further interpretation of the other sculptures would have to be made in terms of the four elements. The central motif of the *Parterre d'Eau* was complemented by two other motifs: An enormous globe was supposed to be erected in the area directly in front of a passage leading down to the Latona fountain. It was then to be surrounded by figures representing Africa, Asia, America, and Europe.

The castle was closely connected to the arrangement of the *Parterre d'Eau* in front of it. Personifications of the twelve months were situated in front of the garden façade. Sculptures representing Apollo and Diana, who, as a description from 1681 pointed out, rule over the year,[44] were also added to them. According to this plan, the *Parterre d'Eau* included a wide range of sculptures. Its uniqueness, however, lay in its referential system. The experts responsible for questions of representation were seeking to combine the representation of Louis XIV with a scientific descreption of the world.

World Interpretation within Circle and Square

The *Parterre d'Eau* initially attracted attention due to its unique structure. Placed upon a square base, the five basins thus connected two geometrical forms, the circle and the square. Therefore, the ground plan had already become part of the thematic aim of the ensemble, since the motif was based on the iconographic representation of microcosm and macrocosm. Yet focussing only on this element would leave the *Parterre* too abstract. Both the dramatically depicted abduction scene at the four corner points, and the single sculptures intended to embody visual themes, limited the possibilities for interpretation. For the shape and content of the *Parterre d'Eau* referred to a special motif and pictorial language concerning the scientific representation of human and cosmos with the four elements, the temperaments, the daytimes and the months. The charts and illustrations, in scientific publications of the

[43] Francastel P., *Girardon* (Paris: 1928) 19–21; Weber G., *Brunnen und Wasserkünste in Frankreich im Zeitalter Louis XIV* (Worms: 1985) 115.

[44] Morellet L., *Explications historique de ce qu'il y a de plus remarquable dans la maison royale de Versailles* (Paris: 1681) 72.

early modern era, in particular developed a systematic iconography. A recurring representational mode can be observed that analyzes the effects of microcosm and macrocosm by focussing on the geometrical forms of the circle and square. A few examples should suffice to provide an overview of these of scientific figures. The schematic summary of the relationships between world, year, and man is stunningly exemplified in Isidore of Seville's *De natura rerum* and it contains images which had a large impact on the following centuries. A 13th-century manuscript depicting the cosmological scheme of Thomas of Cantimpré's *Liber de rerum natura* provides an additional example[45] and encourages the iconography of circle und square in alliance with a scientific form of explication. The outer and inner sections are hierarchically related to each other, whereas in these scientific illustrations, as in Isidore and Cantimpré, the progress of influence must lead to the centre as a point of great importance.[46] This example by Isidore, which bears the word *mundus*, was established as a motif that provided viewers immediate insight into the modes of operation for both the world and the cosmos. Two examples of this general image tradition for the configuration of the *Parterre d'Eau* will be considered in the following.

French cosmographer Oronce Finé commissioned a depiction of the four elements and their modes of operation to illustrate his book *Protomathesis*, published in Paris in 1532.[47] In the elaborate drawing, two squares are inscribed inside a circle but do not fill the circle. The first square, located at one of its corners, is dedicated to fire, air, water, and earth. The second, at right angles to the first one, is the area of heat, dryness, wetness, and cold. The elements of both squares were related to each other in terms of equivalence and contrast. Furthermore, the outer circle brings the squares together by quoting the connecting and differentiating line of reasoning *summa* or *remissa*. The motif, at the center of which a crowned dolphin can be seen, was probably made by Finé himself and, was published widedly.[48] It was used by the Jesuit

[45] On this topic see Patschovsky A., *Die Bildwelt der Diagramme des Joachim von Fiore. Zur Medialität religiös-politischer Programme im Mittelalter* (Ostfildern: 2003).

[46] Bogen S. – Thürlemann F., "Jenseits der Opposition von Text und Bild. Überlegungen zu einer Theorie des Diagramms und des Diagrammatischen-", in *Patschovsky* 1–22, especially 6.

[47] About Finé see Heninger S.K., *The cosmographical glass. Renaissance diagrams of the universe* (San Marino: 1977) 39.

[48] Ibid., 106–108.

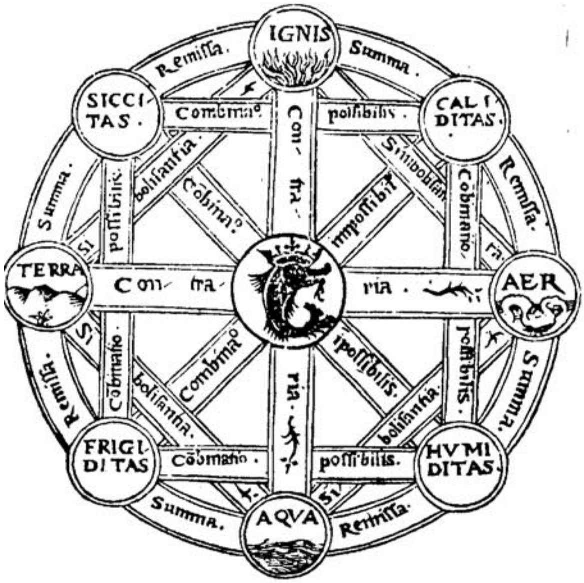

Fig. 12. Oronce Finé, *"Protomathesis"*, 1532, woodcut, from: Heninger S.K., *The cosmographical glass. Renaissance diagrams of the universe* (San Marino: 1977) 106.

Fig. 13. Christopher Clavius, *"In sphaerum Joannis de Sacro Bosco commentarius"*, 1581, woodcut, from: Heninger S.K., *The cosmographical glass. Renaissance diagrams of the universe* (San Marino: 1977) 166.

Christopher Clavius in his book *In sphaerum Joannis de Sacro Bosco commentarius*, published in Rome in 1581.

Clavius replaced the dolphin with the letters IHS, the Greek abbreviation for Christ, thus emphasizing the fundamental significance of salvific history for the mode of operation of the microcosm. In the 17th century, Finé's scheme was also added to an unauthorized reprint (published in Frankfurt am Main in 1690) of Leibniz's *Dissertatio de arte combinatoria*, which had been completed in 1666. The centre, apparently multifunctional, was now decorated with a flower, thus eliminating the Christian character of the picture. Leibniz's sojourn in Paris from 1672 to 1675 took place at a time when the planning and execution of the *Parterre d'Eau* in Versailles had just begun. His contributions included ideas concerning the effects of the four elements, which were still current around 1670. In addition to this, it can be assumed that Leibniz would have heard of the project through his contact with members of the *petit académie*, the *Académie des sciences*, and Claude Perrault. Regardless of whether Leibniz was involved in the project planning of the *Parterre d'Eau* or not, it is important to mention that in his writings, he emphasizes that its mode of representation was valid.

Another fairly elaborate example demonstrates the interconnection between the four elements and a pictorial language in this scientific context which uses the motif of circle and square. The so called *Mundus Elementaris* table, produced by the school of Johann Theodor de Brys, described nothing less than the functioning of the world and the cosmos.

This folding table was first published in the appendix of *Dyas Chymica Tripartia* in Frankfurt am Main in 1626. Its scientific validity in the 17th century was confirmed by its reprinting in the *Museum Hermeticum* in 1677. The table can be understood as the sum of the efforts to represent the powers of nature and the cosmos using geometrical images. The *Mundus Elementaris* engraving unites the four elements with the winds as a defining power.[49] The illustration is separated into fifteen circles which surround a central medallion, which depicts a naked figure whose arms are being held by two angels. The figure symbolizes *Anima*, i.e. the soul of the world. Next to it is an inscription and a circle, decorated with stars and inscribed with the word NATURA. This circle, in turn, is

[49] Le Brun integrated Zephyros, which is not mentioned in the metamorphoses, to the group with Boreas. In this way he can make a link to the theme of the major winds.

Fig. 14. Johann Theodor de Bry, *"Mundus Elementaris"*, 1625, etching, (Herzog August Bibliothek Wolfenbüttel, Nd 779).

surrounded by twelve segments denoting *Alchymia, Gramatica, Dialectica, Rhetorica, Musica, Physica, Astronomia, Arithmetica, Geometria, Medicina, Iurisprudenta* and *Theologia*. In this way, reference is made for example to the three ages, the three worlds and the three regencies. The next visual sequence is directly related to the elements. The seven planets indicate the element of water, which itself refers to winter and melancholy. The seven archangels *Gabriel, Raphael, Anael, Michael, Samuel, Zachariel* and *Oriphiel* are followed by both the element of fire and spring as well as the phlegmatic temperament as characterized by its juice *Pituita*. The seven metals *Plumbum, Stanuum, Ferrum, Aurum, Cuprum, Argetum Viuum, Argentum* are assigned in this example to the element of water, which here refers to autumn and the sanguine temperament. The seven *Membra Microcosmi* as *Splen, Herar, Fel, Cor, Renes, Pulmo*, and *Cerebrum*, the summer, the choleric temperament, and the element of air conclude the segment. The zodiac signs, depicted in two representational modes, then complete this section. The *Mundus Elementaris* circle is followed by the four main ancient winds, which show the points of the compass at the same time: Boreas/north, Euros/east, Notos/south, Zephyros/west. They enclose the central circle using a surrounding square. The *Mundus Elementaris* depiction must be regarded as one of the most pronounced attempts to represent the entirety of nature and the cosmos in its connection to the human life by means of a systematic image emerging from geometry and emblems.[50] For it is the four elements that locate the human being in the centre of their modes of operation. The parallels between the formal arrangement of the *Mundus Elementaris* and the design of the *Parterre d'Eau* is quite extensive. As mentioned above the Versailles grounds also include the four points of the compass and the *artes liberales* with the muses, the elements, the temperaments, the daytimes and the months. The connection to the garden façade of the château also becomes evident through the zodiac signs of the *Mundus Elementaris*. A scheme like the one found in *Dyas Chymnica Tripartia* and the ones used by Finé, Clavius, and Leibniz enabled both the content and the visual representation of knowledge to be immediately understood. Something similar can be seen in the *Parterre d'Eau* as the figures as symbolic and sensuous substitutes were related to each other in terms of space and subject. Both the *Mundus Elementaris* table and the *Parterre d'Eau* present an image that symbolizes the entirety of world: "une représentation

[50] Böhme – Böhme, *Feuer, Wasser, Erde, Luft*, 233–241.

de toute la masse ou construction universelle" as Claude Nivelon puts it. In this way, the construction of *Parterre d'Eau* would be immediately understood by the educated viewer. This methodical approach was also followed by Leibniz, who emphasized the immediate perception of this kind of scientific demonstration.[51] For this he developed the concept of the *coup d'oeil*, which suggests that pictures are able to communicate their knowledge directly.

The schematic depiction of the four elements' modes of operation in the microcosm and macrocosm testify to the dogged nature of the quest for knowledge at a time when the separation of scientific disciplines and the partition of the arts had not yet occurred. This division was even being actively struggled against in pictures of the highest quality.

In *De regimine principum*, Thomas Aquinas pointed out the socio-political implication of the elements by explaining the different positions of the social stratification according to a ranking of fire, earth, water, and air. The Parisian theologian Jean Michel, in his book *Anatome corporis politici*, published in 1564, related the human body to the state with a reference to Aristotle, creating an analogy describing how the elements related to one another. In *De republica*, published in 1596, Pierre Grégoire also politicized this complex set of relationships by assigning a harmonic relation to state unity.[52] It should become clear, even after only a brief description, that the four elements were also of great importance in the early modern era for describing the constitution of the human society. Visual references concerning both the doctrine of the four elements and the description and representation of authority could be observed in various places. For example, this tendency could be seen in Antwerp in 1561–62 when Marten van Heemskerck documented festive processions in his series of engravings entitled *Circulus vicissitudinis rerum humanarum*. The *Studiolo* of Francesco I Medici in the Palazzo Vecchio, Florence provided yet another example.[53] This *Studiolo*, dedicated to the four elements, was presented as an exclusive model of the world, and the arrangement of the objects can be connected to the power of the ruler. The political motifs of fire, earth, water, and air,

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[51] For the topic of the so-called *coup d'oeil* Bredekamp H., *Die Fenster der Monade. Gottfried Wilhelm Leibniz' Theater der Natur und Kunst* (Berlin: 2004) 113–115.

[52] Peil 1996, 220–224.

[53] Liebenwein W., *Studiolo. Die Entstehung eines Raumtyps und seine Entwicklung bis um 1600* (Berlin: 1977) 154–158.

as they describe the functionality of nature as well as human society, were also employed in representations of the French state.

In contemporary commentaries describing the sovereignty, the French king was considered the *premier cause* of all efforts. This idea could thus be visualized in the *Parterre d'Eau* with Apollo, the visual representative of Louis XIV, who was located in the center. However, there was an attempt to connect this thought to a schematic view of the world that, in the late second half of the 17th century, had finally lost its validity.[54] The scientific doctrine of the four elements, upon which the Versailles grounds was clearly based, was no longer binding.[55] Its explanatory power in particular, which was able to expose the effects of the microcosm and macrocosm, simply did not exist any more at the end of the century. Fire, earth, water, and air still functioned as parts of an allegorical political symbol system but no longer served to illustrate the proposition that the monarch was equal to god. Thus in Versailles, the heart of the French state, the idea of representing the king in connection to the four elements was doomed to failure. This conflict between a scientific and a political attempt to describe the functionality of nature and human society was considered carefully by the French government with respect to its susceptibility to the approaching changes. After eleven years, the construction of the *Parterre d'Eau*, which had nearly been completed, was abandoned in 1683. The construction was then altered to depict the main rivers of France. The world model originally planned was replaced by a representation of the economic veins of france and the representation of the monarchy embodied by Louis XIV was stripped of all its mystery.

[54] 'Wenn eine überholte politische Theorie mit einem nicht mehr allgemein anerkannten naturwissenschaftlichen Weltbild begründet und bewiesen werden soll, ist diese Unternehmung zum scheitern verurteilt.' Peil 1996, 237.

[55] Böhme – Böhme, *Feuer, Wasser, Erde, Luft*, 132.

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